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ENVIRONMENTAL ASSESSMENT FOR THE FERTILIZATION OF THE OVERTON ARM OF LAKE MEAD (NEVADA), 1988 AND 1989

NATIONAL PARK SERVICE
LAKE MEAD NATIONAL RECREATION AREA

With Concurrence Of

LOWER COLORADO REGION
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1. INTRODUCTION

This Environmental Assessment (EA) has been prepared in compliance with the Council of Environmental Quality (CEQ) regulations implementing the procedural provisions of the National Environmental Policy Act (NEPA), as amended of 1969. The EA considers action proposed for years two (1988) and three (1989) of a planned 3-year program of experimental fertilization of the Overton Arm of Lake Mead. The program is designed to investigate the feasibility of using artificial fertilization to increase the forage base available to the principal game fishes of this reservoir.

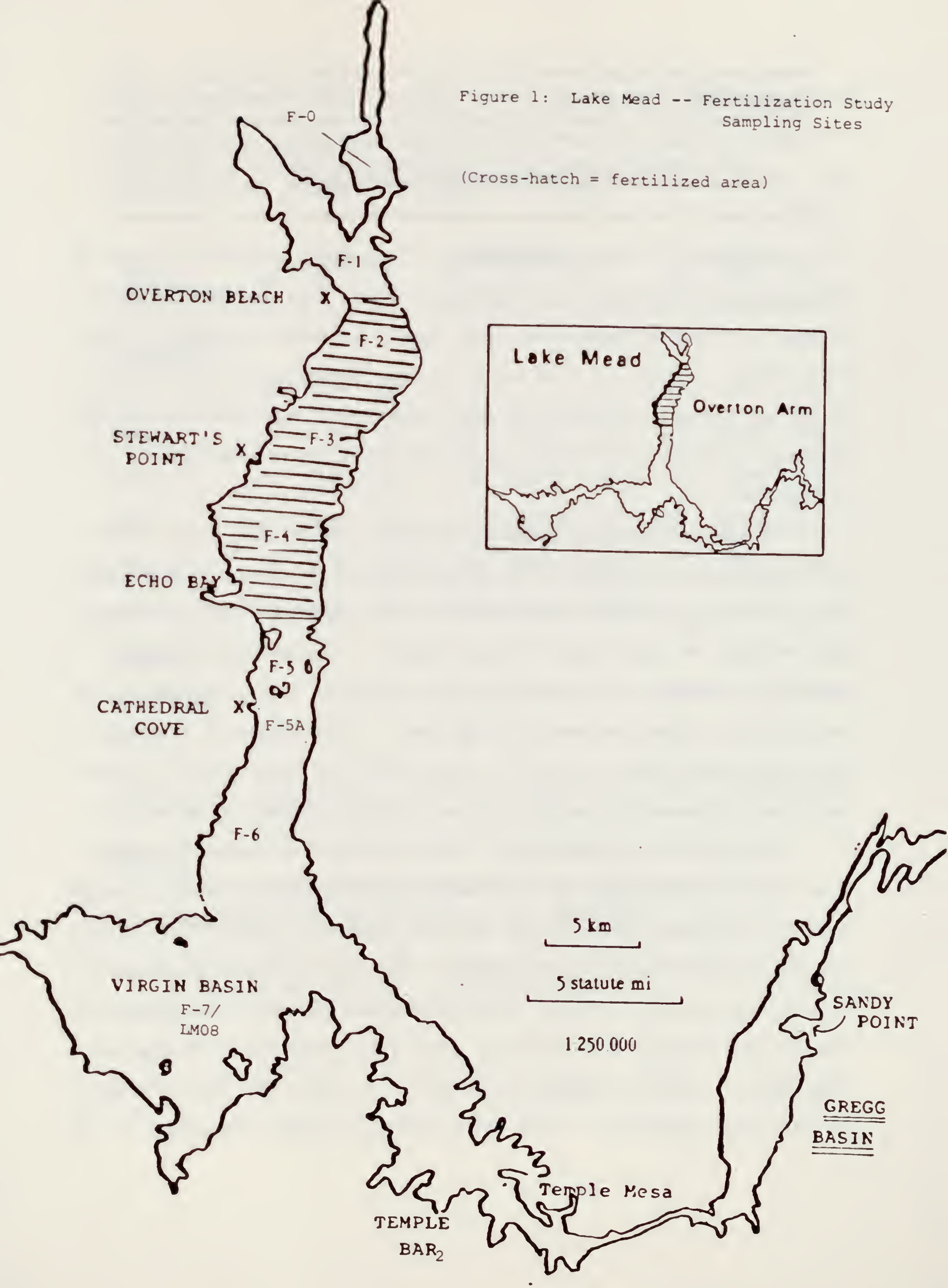
A variety of baseline historical data analyses and field studies of the water quality and aquatic ecology of Lake Mead have documented a substantial decline in primary (algal) production in Lake Mead over the past two decades and have indicated this to be a major factor in the decline in the fisheries (see Appendix 1). The first year of the proposed 3-year experimental program was carried out in 1987 following the issuance by the National Park Service (NPS) of a Finding of No Significant Impact (FONSI) for the 1987 experiment, based on the EA prepared at that time.

The proposed action is to add up to 25,000 gallons of liquid ammonium polyphosphate to the Overton Arm of Lake Mead (Fig. 1) in each of the years 1988 and 1989, and to intensively monitor the effects of these additions on water quality and on biological production at various trophic levels of the Lake Mead ecosystem.

Section 2 of this EA provides a background summary of the fertilization project through 1987. Sections 3 and 4 present an overview of the proposed 1988 and 1989 experiments, and sections 5 and 6 address the environmental impacts.

Figure 1: Lake Mead -- Fertilization Study Sampling Sites

(Cross-hatch = fertilized area)



2. BACKGROUND

2.1 Trends in Productivity and Fisheries in Lake Mead.

Fish yield in lakes and reservoirs is directly related to levels of phytoplankton standing crop and productivity (1-5). In Lake Mead, historical changes in the shad population have closely paralleled changes in algal productivity. Appendix 1 (Section I) provides a detailed discussion of the historical trends in productivity and fisheries in Lake Mead and presents pertinent literature citations. The following is an overview of this information.

Nitrogen and suspended sediment loading in the Colorado River inflow of Lake Mead varied in relation to spring runoff until the closure of Glen Canyon Dam in 1963, which cut off the phosphorous rich sediments that historically had enriched the upper basin of Lake Mead. This upstream reduction in phosphorus loading was accompanied by a decrease of up to 80% in the productivity of the upper basin of Lake Mead. In Boulder Basin, productivity decreased significantly during the late 1970's and early 1980's following reductions in phosphorus loading from the tertiary treatment of wastewaters.

These declines in productivity, and associated food resources, appear to have had an adverse impact on the limnetic shad populations, the main forage base for largemouth bass, striped bass and salmonids. Most of Lake Mead is now oligotrophic (Table 1). The limnetic areas are very low in phosphorus and productivity, and are virtually devoid of plankton and shad. The inflow areas are the only locations in Lake Mead where algal productivity is apparently high enough to sustain zooplankton production at levels resulting in moderate to high shad densities. These areas comprise a small percentage of the

Table 1 Trophic state of Lake Mead during 1981/1982 and during the 1986 growing season relative to classification criteria found in the literature. Data from 1981/1982 based on area weighted monthly surface composites (0-5m) from all lake stations. 1986 data are averages based on monthly surface composites from May-September from Virgin Basin, three Overton Arm stations, and Gregg Basin O= oligotrophic, M=mesotrophic, E=eutrophic TP and chlorophyll-*a* in ppb, and secchi depth (transparency) in meters.

SOURCE	TP			CHLOROPHYLL			SECCHI		
	O	M	E	O	M	E	O	M	E
Criteria(cite):									
(1)	<12	12-25	>25	-	-	-	-	-	-
(8)	<12	12-24	>24	<2.5	2.5-6.5	>6.5	>4.0	2.0-4.0	<2.0
(13)	<15	15-25	>25	<3.0	3.0-7.0	>7.0	>4.0	2.5-4.0	<2.5
(35)	<10	10-20	>20	<2.0	2.0-6.0	>6.0	>4.6	2.7-4.6	<2.7
(38)	<10	10-20	>20	<7.0	7.0-12	>12	3.7	2.0-3.7	<2.0
(39)	<10	10-30	>30	0.3-3.0	2-15	10-500	-	-	-
Lake Mead:									
1981-1982	9			1.5			9.5		
1986	9.2			<2			~5		

Citations

(1) = Ahl and Wiederholm 1977. (8) = Carlson 1977. (13) = Forsberg et al 1978
(35) = Rast and Lee 1978. (38) = U.S. EPA 1974. (39) = Wetzel 1983

NOTE: Citation numbers refer to "Literature Cited" section of January 1988 proposal (Appendix 1 of this EA).

surface area of Lake Mead.

Major changes have also occurred in the Lake Mead sports fisheries over the past two decades. The once famous largemouth bass (*Micropterus salmoides*) fishery began to decline in the late 1960's following the construction of Glen Canyon Dam in 1963, 456 km upstream. Striped bass (*Morone saxatilis*) and salmonids, primarily rainbow trout (*Salmo gairdnerii*),were introduced in 1969 to supplement the failing bass fishery. The trout and striped bass fisheries flourished during the early and mid 1970's, respectively. However, the trout fishery collapsed after 1976 and condition factors of striped bass began declining after 1979. By the early 1980's emaciated stripers were prominent in the population. The largemouth bass fishery continued its decline during the 1970's.

Fisheries and limnological studies conducted over the past decade (described in Appendix 1) have indicated that decreases in planktonic productivity and the forage base have been a major factor responsible for the fisheries problems in Lake Mead. These problems have generated a lot of concern from sportsmen and are the focus of the proposed 1988 and 1989 research program.

2.2 Artificial Fertilization: Preliminary Studies and the 1987 Environmental Assessment.

Following the completion of a five year study analyzing the factors potentially responsible for the decline of the largemouth bass fishery in Lake Mead, the Arizona Game and Fish Department (AGFD) and the Nevada Department of Wildlife (NDOW) recommended that experimental fertilization be conducted in the upper basin of Lake Mead to evaluate this method for restoring the forage base (6). In 1984, the Lake Mead Nutrient Enhancement Technical Committee

(LMNETC) was formed in order to develop plans for an experimental program of artificial fertilization. This committee was composed of biologists and limnologists from the following state and federal organizations: NDOW, AGFD, NPS, U.S. Bureau of Reclamation (USBR), Nevada Division of Environmental Protection (NDEP), U.S. Fish and Wildlife Service (USFWS) and the University of Nevada ,Las Vegas (UNLV). In 1986, USBR funded the Limnological Research Center of UNLV to conduct laboratory and pilot-scale field experiments designed to evaluate the potential for successfully stimulating algal growth on a large-scale in Lake Mead using artificial fertilization (7; see also Section IC of Appendix 1). Two principal recommendations of the Pre-Fertilization study were:

1. Use commercially available liquid ammonium polyphosphate (10-34-0 "white" formulation), and
2. Conduct the first large-scale test in the Overton Arm in May.

These and other conclusions of this study were directly incorporated into the design of the 1987 Overton Arm Fertilization and the proposed second and third years of the 3-year experimental program.

UNLV submitted to LMNETC a formal proposal for fertilizing the Overton Arm and Gregg Basin of Lake Mead in January 1987. Gregg Basin was subsequently dropped from the proposal because of inadequate funding. An EA for the 1987 experiment (8) was submitted to NPS and distributed for review in March. After reviewing public comments, NPS authorized a FONSI on May 21, 1987 and granted UNLV permission to proceed with the test contingent upon issuance of a National Pollutant Discharge Elimination System (NPDES) permit. Application for the latter permit had already been made by UNLV to the Nevada Division of Environmental Protection (NDEP). Following a 30 day comment period and a public hearing, NDEP issued the NPDES permit (#NV0021393) to UNLV on May

27, 1987. The NPDES permit specified effluent limitations, monitoring requirements and conditions, and submittal of a final data report prior to October 27, 1987. This report (9) was submitted and accepted by NDEP in fulfillment of the monitoring requirements of the permit.

2.3 The 1987 Overton Arm Experiment: Overview of Methodology and Results.

The principal objectives of the 1987 experiment, the first large-scale fertilization of Lake Mead, were:

- Develop application procedures for uniformly dispersing nutrients in the test region.
- Boost phytoplankton biomass and productivity to moderate (mesotrophic) levels for a relatively short period of time (several weeks).
- Intensively monitor algal and zooplankton responses to fertilization.
- Intensively monitor water quality in the test region and in control regions in order to assess effects on other beneficial uses of the lake.
- Develop base-line information on the relative abundance and condition of the primary pelagic forage and predator species in Lake Mead, especially within the test and control regions of the Overton Arm.

On May 30, 1987, 1000 volunteers in 300 boats added 20,000 gallons of liquid ammonium polyphosphate fertilizer (10-34-0) to about 20,000 acres of the Overton Arm. The application procedure worked extremely well and intensive monitoring showed that the fertilizer quickly mixed to a depth of about 10 m across the test area. Table 2 summarizes the extensive limnological data base that was developed through monitoring the test and control areas of the Overton Arm during the periods prior to and following fertilizer application. This data base is discussed in detail in Appendix 1 (Section II) of this EA.

In summary, it was found that the added nutrients were rapidly assimilated by phytoplankton. Chlorophyll-a increased to moderate levels

Table 2. Changes in certain limnological parameters in the fertilized region (mean values from 0-5m composites from stations F-2/3/4) following the 1987 Overton Arm Fertilization. ✓ = *as predicted in the Lake Mead Fertilization Project Environmental Assessment* (LMNETC , 1987).

PARAMETER	(5/14-5/27) PRE	(5/31-6/16) FERT	(6/24-7/8) POST	NOTES
Total-P (ppb)	7-11	46 max, 23 mean (day 1)	7-13 (day 8)	✓, slightly higher TP due to stratification pattern
NH_4-N (ppb)	< 10	24 max (day 1)	< 10 (day 2)	✓
NO_3-N (ppb)	150-180	depletion to <20	<20	✓, rate of depletion increased from -3-14 gN/L/day
Total -N	.... no significant effects			✓
pH	8.4-8.6	8.4-8.8	8.4-8.5	✓
EC	~815-850 : no effect due to fertilization			✓
DO (ppm)	saturated	supersaturated (120-150% @ midday)	saturated	✓
Chlor-a (ppb)	<2	3-11 (day 3 to 13)	≤ 2	✓ (>5ppb for 4 days)
Clarity (extinction of PAR, 0-10m, as k, m^{-1})	0.26-0.36 (~30% reduction during the first week, <20% after 2 weeks)	0.37-0.48	0.41-0.27	✓

within a few days, but returned to control concentrations within one month following fertilizer application. The 30-day mean chlorophyll-a concentration in the treatment area during this period was 2.4 ug/l, well below the 5 ug/l chlorophyll-a standard adopted for Lake Mead in September 1987 (see 10). The nutritional state, reproductive rates and densities of zooplankton increased a few days following the algal "peak". Echosounding and mid-water trawling indicated that shad abundance was higher in the fertilized area than it was in control areas or historically in the Overton Arm. Striped bass condition factors increased by about 20% over historical levels for that area and 28% relative to all other combined areas of the lake since 1984.

There were no adverse impacts demonstrated on water quality in Lake Mead. The fertilizer was confined largely to the test region. It did not affect the salinity of the water. No nuisance algae blooms or odors were evident, nor did periphyton growth increase on hulls of moored boats at Echo Bay or Overton marina. There were no demonstrated adverse effects on other recreational uses or on municipal water users downstream, and no complaints were filed with any of the agencies involved in the project.

3. THE PROPOSED 1988 AND 1989 EXPERIMENTAL FERTILIZATIONS OF THE OVERTON ARM OF LAKE MEAD.

3.1 Purpose

The proposed 1988 and 1989 experimental fertilizations of the Overton Arm of Lake Mead represent the final two years of a 3-year experimental research program. The research is designed to test the scientific feasibility of increasing forage (shad) biomass by inducing moderate, short-term increases in primary production, but without causing adverse impacts on other beneficial uses of Lake Mead water. The ultimate objective of this program is to evaluate the potential contribution of artificial fertilization as a future management tool for improving both the quantity and the quality of the Lake Mead fisheries. Predictive calculations based on ecological theory suggest that addition of the proposed quantity of phosphorus could increase shad biomass by a significant amount relative to "background" levels present in the lake (Appendix 4).

Based on specific concerns of downstream water users (see Section 6), a major scientific objective of this research program is to collect sufficient data to enable an informed judgement to be made about the magnitude of potential adverse impacts on water quality. Data collected during the 1987 experiment demonstrated that fertilization did not produce any measurable impacts on threshold odor number or salinity in either the treatment area or downlake. The 30-day mean chlorophyll-a concentration did not exceed the standard for Lake Mead (Appendices 1 and 3). Concerns of downstream water users, as voiced in their comments to the 1987 EA (8), focused on these three parameters. In response to more recently voiced concerns, the monitoring program designed for the proposed 1988 and 1989 experimental fertilizations will address water quality issues in greater detail than was the case for the 1987 experiment (see Appendices 1 and 2).

The data obtained from the 1988/1989 research programs will also provide a primary basis for predicting the water quality consequences of any management-oriented (i.e. longer-term and/or increased area) program of lake fertilization should this be considered in the future.

3.2 Need

The sports fisheries of Lake Mead are a major element of the Lake Mead National Recreation Area and, in 1986, experienced an exploitation pressure of over 600,000 angler days. The fisheries represent a resource valued at approximately $70 million per year to the economy of the region (6). In view of the socio-economic value of this resource, the demonstrated declines in the number of largemouth bass harvested and the size and condition of striped bass are of particular significance. The total number of harvested largemouth bass has decreased by over 350,000 (or more than 80%), even as angling pressure increased from about 400,000 angler-days in 1969 to over 600,000 angler-days in 1986. While the number of striped bass harvested has increased since this species became established in Lake Mead in the early 1970's, the condition or "plumpness" of these fish has decreased by over 50% during the past decade (Appendix 1). Furthermore, the weight of the average striped bass in the creel decreased by approximately 70% over the same time period (11). As a result, the estimated total biomass harvested in 1986 was approximately the same as in 1979, even though the number of striped bass harvested in 1986 was greater than in 1979 (see Fig. 1 in Appendix 1). Growth rates of striped bass also decreased considerably during the 1970's and early 1980's (12).

Low abundance of the principal forage, threadfin shad, is thought to be a major factor responsible for the fisheries problems in Lake Mead. One hypothesis for this low forage abundance is that primary production in the lake is too low to sustain adequate levels of shad production, as described in Section 2 of this EA. The 3-year research program is needed in order to test this hypothesis, and will provide data to evaluate the potential for using controlled nutrient additions as a possible management tool for enhancing the forage base of the sports fisheries. In particular, the proposed second and third years of the program are required in order to address, in considerably more detail than was possible during the 1987 experiment, the impact(s) of increased plankton production on shad nutritional state, survival and production. The final two years are also needed to "follow" the pattern of increased striped bass condition factors observed in the Overton Arm in 1987, and to initiate analyses of largemouth bass condition and growth rates. In addition, the proposed research is needed to investigate, for the first time, the possibility of manipulating shad abundance later in the year in order to enhance largemouth bass survival during one of the most critical stages of their life history, i.e. their first winter. During the 1987 experiment, insufficient numbers of largemouth bass were creeled to allow the impact of fertilization on this species to be addressed. Sampling effort, however, will be increased in 1988 and 1989.

It is fully recognized that lake fertility may not be the only factor influencing shad population dynamics in Lake Mead. Climate, predation pressure, and spawning success potentially all impact the abundance of this and other species in the reservoir. A variety of studies (summarized in Section 2 and Appendix 1 of this EA) have indicated, however, that fertility is probably the major factor responsible for the observed low abundance of shad. It is obviously impossible - from any realistic perspective - to address in one 3-year study all of the factors potentially influencing shad population dynamics in Lake Mead. The proposed research, therefore, focuses specifically on the influence of fertility and is designed to provide answers to questions concerning how different levels of planktonic production impact shad and the principal game fish populations of this reservoir.

Lake Mead is a dynamic and artificially created ecosystem, and the sports fisheries were created with introduced species. Management of the system is essential and the effectiveness and appropriateness of management policies depend on being able to make an informed selection from a variety of potential management tools. Artificial fertilization may represent one such potential management tool. This research program is required for the scientific evaluation of this approach, and for ensuring that it can be accomplished without adversely impacting other beneficial uses of the lake.

3.3 Overview of Proposed Research

General Objectives: The primary objective of the proposed 1988 and 1989 research is to continue to evaluate the response of the phytoplankton-zooplankton-shad segment of the food chain to phosphorus addition in a P-deficient region of the lake. The secondary objective is to investigate shad-game fish relationships by collecting information on game fish feeding ecology, nutritional condition and growth rate.

Research Design: We propose to conduct the research for both 1988 and 1989 in three segments:

A. Fertilization of 18,950 acres of the Overton Arm (the same area that was used for the 1987 experiment) in May to a level of 15 ppb phosphorus, using 15,000 gallons of ammonium polyphosphate.

   This application is essentially a repeat of the 1987 experiment and will provide the opportunity for increasing the detail of investigation into how fertilizer application affects production processes at various trophic levels.

B. Fertilization of the same area of the Overton Arm to a level of 5 ppb in June, using 5000 gallons of ammonium polyphosphate.

   This application is designed to investigate if a much lower phosphorus "spike", applied at a time when zooplankton densities are naturally low in Lake Mead, can have a measurable effect on zooplankton production and shad nutrition.

C. Fertilization of selected coves to a level of approximately 20 ppb in the fall, using up to 5000 gallons of ammonium polyphosphate.

> This application in 1988 constitutes a pilot experiment and will address the possibility of manipulating food resources for shad and largemouth bass as they enter the critical winter period.

Appendix 1 (Sections IV and V) provides details of the proposed 1988 research plan. Modifications/additions to the January 1988 proposal are included in Appendix 2 of this EA. Research in 1989 will essentially follow the 1988 proposed program, although certain components may be modified based on the 1988 data base. However, the 1989 experiment will involve no significant change from 1988 in the total fertilizer loading, or in the overall objectives of the research.

(Note: Any significant reduction in the volume of water contained in the treatment area, as a result of lower lake levels would be compensated for with a corresponding reduction in the fertilizer load. The concentrations of the proposed "spikes" will be maintained).

4. ALTERNATIVES

Alternative A: Action - Spring/summer fertilization of 18,950 acres of the Overton Arm with a total of 20,000 gallons of fertilizer; fall fertilization of selected coves with approximately 5000 gallons of fertilizer.

Alternative A represents the experimental design proposed for this research and described in above Section 3.3. Consistent with a) maintaining the overall integrity of the 3-year program, b) providing some degree of between-year replication, and c) optimizing the amount of information obtained from three years of experimentation, we believe that this research design constitutes the most scientifically sound approach for completing the experimental program.

Alternative B: Action - Fertilization of a region of Lake Mead according to an experimental design that differs significantly from that proposed in Alternative A.

Numerous alternative designs for fertilizer application to the lake are theoretically possible, in which i) region of application, ii) area of treatment, iii) nutrient loading, and iv) timing of application are all varied, singly or in combination.

Adoption of any one of these alternatives would substantially reduce the scientific integrity and overall utility of the 3-year research program. It is essential that the treatment area for the May/June fertilization be kept the same for the 1988 and 1989 experiments as it was in 1987. Any substantive change in the region fertilized would significantly compromise between-year data comparisons across the longitudinal series of monitoring stations. Furthermore, a substantial reduction in the area to which fertilizer was added would greatly decrease the potential for studying the relationship between planktonic production and shad biology, given the fact that larval and juvenile shad probably exhibit more than small-scale horizontal movement in the pelagic zone. An increase in the treatment area is unwarranted for the present research objectives and is also economically not justifiable. Alternative B is therefore rejected.

Alternative C: Action - Fertilize the Overton Arm according to the design proposed in Alternative A, but with the use of a "curtain" to physically separate control from treatment areas.

Any medium to large-scale *in situ* experiment, such as the Overton Arm Fertilization, must address the definition of adequate controls that will allow the separation of experimental from natural or background variance. Although this makes *in situ* experiments more difficult to design than laboratory ones, the former are essential in order to investigate the relevance of results obtained from laboratory and pilot-scale studies to i) the set of ultimate objectives (in this case fisheries improvement) and ii) "real-world" conditions.

The installation of a "curtain" to physically separate control from treatment areas is unfeasible from many perspectives, including economic and "environmental". Furthermore it is considered to be unnecessary for this research program. The design proposed under Alternative A includes both temporal and spatial controls for the experimental treatment that are considered adequate (see Apendices 1 and 2). Alternative C is therefore rejected.

Alternative D: Action - Fertilization of cove areas only.

Fertilization of cove areas would not enhance food abundance for the larval and juvenile stages of threadfin shad inhabiting the pelagic region of the lake. Thus Alternative D would not allow one of the central hypotheses of the research program to be tested, i.e. that enhanced planktonic production can increase nutritional condition and survival of shad early in their life history. Alternative D is therefore rejected.

Alternative E - No Action - Experimental fertilization is not carried out.

The "No-Action" alternative to this research would essentially mean that no significant steps would be taken to investigate -- from a scientific viewpoint-- this potential management tool for reversing the trend of declining fisheries in Lake Mead. It would mean that the extensive data base resulting from the proposed experiments would not be available for input into future management decisions. We note that this data base would also be unavailable for input into an assessment of potential water quality impacts resulting from any longer-term, management oriented program of nutrient enrichment, should this be proposed in the future.

Selection of Alternatives for Further Consideration: Alternatives B, C, and D are incompatible with the objectives and scientific integrity of the research program. They are therefore not considered further. Discussion of environmental impacts in Section 6, below, refers only to Alternatives A ("Action") and E ("No Action").

5. DESCRIPTION OF THE EXISTING ENVIRONMENT

The Overton Arm of Lake Mead extends approximately 35 km from the Colorado River channel in Virgin Basin to the mouths of the Virgin and Muddy Rivers. The proposed fertilization area is comprised of a 16 km reach of the area extending from just north of Echo Bay to a point south of the Overton Marina (Fig. 1). It encompasses an area of 18,950 acres, which is about 12% of the surface area of Lake Mead. Thermal stratification develops at a depth of about 13 m in summer. The epilimnion volume in the fertilization area is 692,000 acre-feet or about 2% of the entire volume of Lake Mead.

Water quality in the proposed fertilization area is typical of most areas of Lake Mead. The water is alkaline (pH 7.6-8.3) and fairly high in total dissolved solids (TDS) (550 mg/l). TDS is slightly higher in the northern-most part of the Overton Arm due to saline inflows from the Virgin and Muddy Rivers. The principal constituents of TDS are the anions sulfate > carbonate > chloride, and cations sodium > calcium > magnesium > potassium.

Total nitrogen concentrations in the arm are moderate (0.2 - 0.5 mg/l) but total phosphorus concentrations are very low (0.01 mg/l). Phytoplankton productivity is low with chlorophyll -*a* concentrations averaging about .001 - .002 mg/l during the summer. Oxygen concentrations are usually at or near saturation in the epilimnion and rarely drop below 5 mg/l in the hypolimnion. Transparency of open waters usually exceeds 5 m during summer and can range as high as 15 m in winter. The Muddy Arm, Virgin Bowl and coves on the west shoreline frequently are very turbid due to resuspension of fine clays during storms.

The fish species in the Overton Arm are typical of the rest of Lake Mead and include largemouth bass (*Micropterus salmoides*), striped bass (*Morone saxatilis*), channel catfish (*Ictalurus punctatus*), black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*) and green sunfish (*L. cyanellus*). The principal forage fish is the threadfin shad (*Dorosoma petenense*), although the red swamp crayfish (*Procambarus clarkii*) is occasionally utilized as forage by largemouth bass and striped bass. No endangered fish are known to presently inhabit in the Overton Arm.

A variety of migratory waterfowl frequently visit the Overton Arm, including eared grebe (*Podiceps nigricollis*), Western grebe (*Aechinocphorus occidentalis*), great blue heron (*Ardea herodeus*), ring-bill sea gull (*Larus delawarensis*), and California gull (*Larus californicus*), and coots (*Fulica americana*) usually inhabit the area year-round.

The shoreline plant community at Lake Mead is typified by tamarisk (*Tamarix ramosissima*), seepwillow baccharis (*Baccharis glutinosa*), *Baccharis emoryi*, desert trumpet (*Eriogonum deflexum*), and arrowweed (*Tessaria serica*). Emergent species are uncommon but include narrowleaf cattail (*Typha angustifolia*), willowweed (*Polygonum lapathifolium*) and *Polygonum* *argyrocoleon.* Submergent aquatic vegetation, such as sago pondweed (*Potomogeton pectinatus*), curly leaf pondweed (*P. crispus*) and spiny naiad (*Najas marina*), is quite common in some coves during the summer.

The Overton Arm, like the rest of Lake Mead is used extensively by boaters, fisherman, swimmers, water skiers and campers in the summer months. The National Park Service operates municipal water treatment plants at Echo Bay, Overton and downstream marinas to provide potable water supplies for its facilities and concessionaries. Water supplies for Las Vegas, Henderson and Boulder City are withdrawn 80 km downstream at Saddle Island by the Southern Nevada Water System. Downstream from Hoover Dam, water is diverted for Arizona and California via the Central Arizona Project and the Colorado River Aquaduct, about 320 km downstream of the Overton Arm.

6. ENVIRONMENTAL IMPACTS OF THE ALTERNATIVES

Table 3 summarizes the environmental impacts of alternatives A and E. Pertinent aspects are discussed in detail below. Cumulative impacts are discussed under a separate category (N).

The environmental impacts addressed in this section include the series of concerns raised by persons attending a scoping meeting for this EA, convened by the National Park Service on 18 March, 1988. The list of persons attending this meeting appears in Appendix 5.

TABLE 3

ENVIRONMENTAL IMPACTS OF THE ALTERNATIVES. SUMMARY OF IMPACTS ON NATURAL/CULTURAL ENVIRONMENTS.

Key: + = positive
- = negative
o = no effect

BEN = beneficial impacts
ADV = adverse impacts/worst-case scenario
D = direct effects
ST = short-term effects
LT = long-term effects
CUM = cumulative effects
IND = indirect effects

Note: Table summarizes the perceived impacts arising from the proposed 1988 and 1989 experiments. The text provides, where necessary, a discussion of the rationale underlying impact predictions.

Impacts On:	Alternative A - Fertilization							Alternative E - No Action						
	BEN	ADV	D	ST	LT	CUM	IND	BEN	ADV	D	ST	LT	CUM	IND
A. Vegetation	+	o	+	+	o	o	+	o	o	o	o	o	o	o
B. Terrestrial wildlife	+	o	o	+	o	o	+	o	o	o	o	o	o	o
C. Aquatic Wildlife/ Fisheries	+	o	o	+	o	o	+	o	o	o	o	-	o	-
D. Endangered/Threatened Species	o	o	o	o	o	o	o	o	o	o	o	o	o	o
E. Water Resources														
1. Quantity	o	o	o	o	o	o	o	o	o	o	o	o	o	o
2. Quality	o	o	o	o	o	o	o	o	o	o	o	o	o	o
F. Floodplain/Wetland	o	o	o	o	o	o	o	o	o	o	o	o	o	o
G. Soils/Sediments	+	o	o	+	o	o	+	o	o	o	o	o	o	o
H. Noise/Air Quality	-	o	-	-	o	o	o	o	o	o	o	o	o	o
I. Cultural Resources/ Historical Places	o	o	o	o	o	o	o	o	o	o	o	o	o	o
J. Public Health	o	o	o	o	o	o	o	o	o	o	o	o	o	o
K. Aesthetic Values	o	o	o	o	o	o	o	o	o	o	o	o	o	o
L. Economic	+	o	+	+	+	o	+	o	o	o	o	-	o	-
M. Non-Fishing Recreational Usage	o	o	o	o	o	o	o	o	o	o	o	o	o	o

A. VEGETATION

Alternative A - Fertilization: Beneficial (slight).

A small amount of fertilizer might be deposited near the shoreline in the areas where fertilizer is loaded onto boats. Wave action might also introduce small amounts of fertilizer to the shoreline from the pelagic zone, but the amount of nutrients involved would probably be low relative to soil concentrations. Any nutrients introduced to the littoral zone would, however, tend to enhance shoreline terrestrial and aquatic vegetation. This "additional" growth would be beneficial to fish and benthic invertebrates by providing cover and habitat. The additional evapo-transpiration caused by any enhanced vegetative growth would be totally insignificant relative to "normal" evaporative losses from the lake.

Alternative E - No Action: No Impact.

B. TERRESTRIAL WILDLIFE

Alternative A - Fertilization: Beneficial (slight).

An increase in fish production would be beneficial to fish-eating birds, including visiting bald eagles, grebes, cormorants, gulls, herons, etc. Increased plankton and organic matter production would potentially benefit bottom feeding aquatic birds such as ducks and coots. Increased shoreline vegetation (see A, above) would benefit terrestrial wildlife, including bighorn sheep, small mammals, and other terrestrial vertebrates.

Alternative E - No Action: No Impact.

C. AQUATIC WILDLIFE/FISHERIES

Alternative A - Fertilization: Beneficial.

Moderate nutrient enrichment would stimulate algal and zooplankton production at the base of the Lake Mead food chain. This would increase the amount of food available to forage fish such as threadfin shad, which in turn are the preferred diet of the game fish. Increased lake fertility would thus benefit all principal fish species in the lake.

Data collected during the 1987 experiment support this contention. The increased food availability to shad following fertilizer application was correlated with an apparently higher abundance of shad relative to past years and relative to most other regions of the lake in 1987. It is hypothesized that enhanced plankton densities increased shad survival as post-larvae, a stage that is typically considered critical in the life histories of pelagic species. The proposed research will address this hypothesis. Data from the 1987 experiment also demonstrated that condition factors of striped bass were significantly higher in the Overton Arm than elsewhere in Lake Mead in 1987 or lakewide in recent years. The proposed research will further investigate the relationship between forage abundance and striped bass condition, in addition to addressing the forage-largemouth bass relationship.

Alternative E - No Action: Adverse.

Although Lake Mead is characterized by natural variation, as are all ecosystems, analyses of the interrelationships between nutrient loading and productivity indicate that lake fertility, at least in the upper basin, will not increase significantly in the future due to natural causes. Under these conditions of continued low fertility, an absence of artificial fertilization would likely result in further stress to the forage and game fish populations. The "no action" alternative could adversely affect the fisheries in the long term by denying an evaluation of one potential management tool for improving their quality and quantity.

D. ENDANGERED/THREATENED SPECIES

Alternative A - Fertilization: No Impact/ Slight Beneficial.

Consultation between the National Park Service, Lake Mead National Recreation Area, and the U.S. Fish and Wildlife Service, Endangered Species Office, Reno, Nevada, determined that no threatened or endangered fish species are known to currently inhabit the area of the proposed experiments. There would therefore be no impact on any threatened or endangered fish species.

Increased fertility would potentially be beneficial to fish-eating Bald Eagles (endangered) which occasionally visit the lake. No endangered or threatened plant species have been documented to exist along the shoreline of the lake (13).

Alternative E - No Action: No Impact.

E. WATER RESOURCES

1. Quantity

Alternative A - Fertilization: No Impact

Alternative E - No Action: No Impact

2. Quality

Alternative A - Fertilization: No adverse impact.

The monitoring program employed for the 1987 fertilization demonstrated that this experiment did not cause any violation of pertinent water quality standards for Lake Mead (Table 2). Average chlorophyll-*a* levels were well within the chlorophyll standard established for Lake Mead (Appendix 1). Total fertilizer loads for the proposed 1988 and 1989 experiments do not differ substantially from that employed in 1987. There is virtually no potential for the added fertilizer to significantly impact total phosphorus, total nitrogen or chlorophyll concentrations of the lower basin or of Colorado water below Hoover Dam (Table 4).

Potential water quality impacts of the proposed 1988 and 1989 fertilizations are considered below, categorized under the series of beneficial uses of Lake Mead (outside of Inner Las Vegas Bay), as defined by the Nevada Division of Environmental Protection (10).

i) Irrigation: Addition of fertilizer would not measurably affect either the salinity or the proportions of major ions in the water. This was clearly demonstrated for the 1987 experiment (Appendix 3), and the proposed total fertilizer loadings for 1988 and 1989 do not differ substantially from those employed in 1987. Nutrient additions from the proposed experiments

Table 4: Effects of "downlake" horizontal mixing (advection) during the summer and vertical mixing during the fall/winter overturn on concentrations of P and N in the unfertilized waters near the dam.

The table presents the appropriate water volumes for calculating these dilution effects using morphometric data from Lara and Sanders (1970). Volumes assume lake surface elevation at 1200 feet above MSL and a thermocline at 13 m. Two scenarios are presented for estimating worst-case (assuming no losses in the experimental area and no increases in N or P with depth) increases in TP, TN and chlorophyll near the dam and in the dam discharge following overturn, as a result of the proposed spring/summer fertilizer applications.

Table 4

	Overton Fertilization Region	Entire Overton Arm	Virgin + Boulder Basins
Epilimnion Volume (acre-feet)	0.69×10^6	1.09×10^6	3.14×10^6
Total Volume (acre-feet)	----	3.01×10^6	17.37×10^6

Scenarios assume a total spring/summer spike of 20 ppb P and 13 ppb N which is added to water initially containing about 9 ppb TP, 250 ppb N, and 2 ppb chlorophyll-a. Fertilization is expected to increase chlorophyll to a maximum of about 10 ppb based on a regression analysis of historical TP and chlorophyll-a values, and results from the 1987 experiment. 75% of the fertilizer load and most of the fertilizer-induced algal production will be derived from the spring/ summer application; the proposed fall cove application has therefore been omitted from these calculations.

(1) If it all stayed in the epilimnion and dispersed uniformly into the rest of the Overton Arm, Virgin Basin and Boulder Basin, then the concentrations throughout these regions would be:

$$\text{TP} = \frac{(0.69)(29) + (3.54)(9)}{(4.23)} = 12.3 \text{ ppb P}$$

$$\text{TN} = \frac{(0.69)(\sim 263) + (3.54)(\sim 250)}{(4.23)} = 252 \text{ ppb N}$$

$$\text{Chlor-a} = \frac{(0.69)(10) + (3.54)(2)}{(4.23)} = 3.3 \text{ ppb chlor-a}$$

CONCLUSIONS: These represent insignificant increases in TP, TN and chlorophyll in terms of downstream domestic water supply intakes.

Table 4 (continued)

(2) The only way the nutrient spike could potentially impact Lake Mohave and its downstream beneficial uses is for the nutrients to vertically mix into the hypolimnion, since the Lake Mead discharge is hypolimnetic. If the fertilizer was uniformly mixed throughout the water in the Overton Arm, Virgin and Boulder Basins (i.e. at fall/winter overturn), and if hypolimnetic TP, TN, and chlorophyll concentrations were similar to their epilimnetic values, then the final levels after complete mixing would be:

$$\text{TP} = \frac{(0.69)(29) + (19.69)(9)}{(20.38)} = 9.7 \text{ ppb P}$$

$$\text{TN} = \frac{(0.69)(263) + (19.69)(250)}{(20.38)} = 250 \text{ ppb N}$$

$$\text{Chlor-a} = \frac{(0.69)(10) + (19.69)(2)}{(20.38)} = 2.3 \text{ ppb chlor-a}$$

CONCLUSION: There is virtually no potential for the proposed 1988 and 1989 Overton Arm experiments to negatively impact water quality in downstream water supplies.

would be negligible in terms of downstream agriculture.

ii) Watering of Livestock: Fertilization would have no impact on livestock watering.

iii) Drinking water: Based on comments received from water users concerning the 1987 EA, taste and odor was the principal concern with the 1987 experiment in terms of domestic water supply. Threshold odor number (TON) data collected during the 1987 monitoring program indicated that fertilization did not significantly affect odor in the surface water where algal concentrations were highest. The proposed spring/summer 1988 and 1989 experiments will not involve any increase in the total fertilizer load applied to the test area. Thus, there is no reason to suspect that odor will be a problem during these experiments. Since spring/summer applications of phosphorus will be made at *lower* concentrations than was the case in 1987, any *tendency* towards odor production would likely be even less significant in 1988 and 1989.

Fertilization of selected coves in the fall would also have an insignificant effect on water odor. Total algal production stimulated by cove fertilization would be low relative to that stimulated by the spring/summer fertilization, because i) fertilizer applied in the fall would represent just 20% of the total annual fertilizer load, and ii) primary production lake-wide is lower in the fall as a result of reduced solar radiation and lower water temperatures.

Although it is concluded from the available evidence that the proposed 1988 and 1989 fertilizations would not adversely affect taste and odor, the monitoring programs will include collection of samples for TON analysis from both treatment and control regions of the Overton Arm. Planktonic and benthic algal samples will be routinely collected and examined for species potentially causing odor problems. Analyses of water samples for such odiferous compounds as 2-methylisoborneol and geosmin will be undertaken if the situation warrants this procedure. (See Appendices 1 and 2, and Table 5 for details of monitoring program).

The potential impact of the proposed 1988 and 1989 fertilizations on the concentration of trihalomethane (THM) precursors in lake water has been voiced as a concern by downstream water users. None of the comments received by NPS on the EA prepared for the 1987 experiment expressed concerns about THM's. The proposed 1988 and 1989 experiments would *not* produce significantly greater amounts of algae during the main growing season than in the 1987 experiment, since the total fertilizer loading to the test region would not be increased. The proposed fall fertilization of selected coves would, as noted above, produce relatively small amounts of algal biomass relative to the spring/summer fertilization. It is concluded, therefore, that during the proposed 1988 and 1989 experiments, there would be no increase in the potential for THM precursor formation relative to any potential which may have existed during the 1987 experiment. As mentioned previously, no concerns were expressed about this latter potential in comments received concerning the 1987 EA.

Major diversions of Lake Mead water for drinking water supply occur at Saddle Island, located in the lower basin (intake depth at elevation 1018 ft a.s.l., or approximately 187 ft below minimum lake level in 1987), and at Lake Havasu, approximately 200 miles downstream from Hoover Dam.

Average THM concentrations in finished water supplied by major utilities are well within the current federal standard of 0.1 mg/l. At the treatment plant of the Southern Nevada Water System (SNWS), THM concentrations have averaged 0.04 mg/l over the past eight years, and annual mean concentrations in this utility's distribution system have never exceeded the federal standard during this period (14). Total THM concentrations in the distribution systems of the Metropolitan Water District of Southern California exhibited annual running averages of between 0.053 and 0.062 mg/l in the years 1984-1988 (15), again well below the current federal standard of 0.1 mg/l.

It is understood that the U.S. EPA is considering a possible reduction in the THM standard at some future date. However, it is unlikely that a new Maximum Contaminant Level (MCL) will be officially proposed before 1990 and it would not be promulgated until some time after that (16).

In view of all the above considerations, it is concluded that the proposed 1988 and 1989 fertilizations of the Overton Arm would not have a significant (or even measurable) impact on the THM concentrations of downstream drinking water supplies. The expressed concerns about THM's are acknowledged, however, and the monitoring program will address this potential impact. Routine analyses of total THM formation potential will be undertaken on samples collected from both treatment and control areas of the Overton Arm (see Table 5 and Appendix 2 for revised monitoring program for THM precursors).

The proposed fertilizations would not impact domestic water supplies by causing increased calcite deposition. Calcite deposition is a natural process that occurs in many lakes, often during periods of increased primary production (summer) and consequent elevated utilization of dissolved inorganic carbon. During the period of enhanced algal production in the 1987 experiment, a slight increase in pH (0.2 pH units, maximum) occurred in the upper 10 m of the water column in the treatment area, presumably reflecting increased use of dissolved inorganic carbon. A similar increase did not occur at the downlake control station (F-6), and, within two weeks, pH values in the

Table 5 a): Sampling Stations for Certain Water Quality Parameters (see Appendix 2 for more details)

STATION	PARAMETER				
	TON[a]	Algae		Chlorophyll[b]	TTHM
		Plankton[b]	Periphyton[a]		
Overton Intake[c]	X	--	--	X	X
F-2	X	X	X	X	X
F-4	X	X	X	X	X
Echo Bay Intake[c]	X	--	--	X	X
F-6	X	X	X	X	X
F-7	X	X	--	X	X

[a] MIB and geosmin analyses will be carried out if fertilization significantly impacts TON and/or if significant growths of the principal odor-causing algae are observed (see Appendix 2).

[b] Parameter will also be routinely measured at the other sampling stations (F-0, F-1, F-3, F-5A).

[c] Intakes for Overton/Echo Bay marina water supplies.

Note: Samples for TON, phytoplankton, chlorophyll and TTHM's will be collected as 0-5 m depth composites. Periphyton collected as grab samples, as described in Appendix 2.

Table 5 b): Sampling Schedule for Certain Water Quality Parameters

DATE (day#)[a]	PARAMETER				
	TON	Algae		Chlorophyll	TTHM
		Plankton	Periphyton		
Overton Arm[b]					
-20	X	X	X	X	X
0 (May 21)	--	--	--	--	--
+ 3	X	X	X	X	X
+20	X	X	X	X	X
+28 (June 18)	--	--	--	--	--
+31	X	X	X	X	X
Coves (October)[c]					
-10	X	X	X	X	X
0	--	--	--	--	--
+ 3	X	X	X	X	X

a) Revised date for proposed second fertilizer application (1988) is June 18.

b) Samples collected at each of the stations listed in Table 5 a).

c) Sampling at two treatment and two control coves.

treatment area had returned to "background" values (7). Thus, although the tendency for calcite deposition may have slightly increased for a short time in the treatment area, there could have been no effect at downlake water supply intakes.

iv) Recreation Involving Body Contact: Fertilization would produce no increase in fecal coliform numbers. There would be a short-term reduction in water clarity in the treatment area due to increased algal chlorophyll. During the 1987 experiment, clarity decreased by about 30% during the first week after fertilizer application, and by less than 20% during the following two weeks (Appendix 1). As previously noted under section 2.3, algal chlorophyll had decreased to background concentrations within one month following fertilizer application, and water clarity had similarly returned to background levels.

v) Recreation Not Involving Body Contact: No increases in periphyton growth were noted on boat hulls following the 1987 experiment. No change in the fertilizer load to the main treatment area is being proposed for 1988 and 1989 experiments, therefore no periphyton problem is anticipated. The 1988 and 1989 research will, however, monitor periphyton growth following the proposed future fertilizer applications (Appendix 1, Section IV).

vi) Industrial: No impact.

vii) Propagation of Wildlife: No impact, with the exception of a possible slight beneficial effect as described under Sections 6A and 6B.

viii) Propagation of Aquatic Life, Including Warmwater Fishery: Artificial fertilization would improve water quality (food abundance) for threadfin shad at a time when larval stages are present in the open-water zone of the lake.

Alternative E - No Action: No effect on water quality as it impacts any of the beneficial uses of Lake Mead, with the exception of the fisheries (see Section 6C).

F. FLOODPLAIN/WETLAND

Alternative A - Fertilization: No Impact.

Alternative E - No Action: No Impact.

G. Soils

Alternative A - Fertilization: Slight Beneficial.

Fertilization could increase soil and sediment nutrient levels, improving conditions for aquatic and terrestrial vegetation (see Section 6A).

Alternative E - No Action: No Impact.

H. NOISE LEVELS/QUALITY

Alternative A - Fertilization: Slight Adverse.

Minor local impacts due to the presence of about 300 boats near Echo Bay during the actual 1-2 days of fertilizer application.

Alternative E - No action: No Impact.

I. CULTURAL RESOURCES/HISTORIC PLACES

Alternative A - Fertilization: No Impact.

Alternative E - No Action: No Impact.

J. PUBLIC HEALTH

Alternative A - Fertilization: Slight Local Impact/No Impact.

There would be no impact on drinking water (see Section 6Eiii), and no impact on fecal coliform numbers (see Section 6Eiv). The short-term reductions anticipated in water clarity will have no impact on public health.

Alternative E - No Action: No Impact.

K. AESTHETIC VALUES

Alternative A - Fertilization: No Impact.

Alternative E - No Action: No Impact.

L. ECONOMIC

Alternative A - Fertilization: Beneficial.

The use of volunteers to fertilize the Overton Arm would have an immediate economic impact on the surrounding communities via expenditures for lodging, meals, entertainment, fishing supplies, etc. The nature of the "event" would also be likely to attract individuals who might not normally come to the area; regional and national news media would be likely to cover the experiment because of its uniqueness. If the proposed research is able to demonstrate a positive impact of artificial fertilization on the fish populations of Lake Mead, then an indirect and long-term beneficial aspect of the program would be the possibility of considering it as a future potential management tool. Any management strategy that were to improve the quantity/quality of the fisheries would potentially represent a very significant economic contribution to the region.

Alternative E - No Action: No Short-Term Impact; Potential Adverse Indirect Impact Over Long-Term

Failure to undertake the proposed research would mean that no scientific evaluation would be made of this possible management tool for improving the Lake Mead fisheries. In the absence of a successful management policy, the sports fisheries would be unlikely to show any significant improvement in the future, and could decline further. The economic gain to the surrounding area expected from any improvement in the fisheries would thus not be realized.

M. NON-FISHING RECREATIONAL USAGE

Alternative A - Fertilization: No Impact.

There would be no impact to the overall recreational usages of the lake. However, water clarity would undergo a short-term reduction in the treatment area, as noted under Section 6Eiv. There would also be increased congestion at the public use facilities at Echo Bay and within the project area during the days of the spring/summer fertilizer applications.

Alternative E - No Action: No Impact.

N. CUMULATIVE IMPACTS

Alternative A - Fertilization: No Impact/Beneficial.

Lake Mead has a short retention time (3-4 years), and the water column annually mixes from top to bottom, thereby ensuring effective flushing of the entire water volume via Hoover Dam. This means that, with two exceptions, there is no potential for any cumulative, or medium to long-term, impacts to result from the proposed 1988 and 1989 fertilizations. The two possible exceptions refer to i) the potential accumulation of fertilizer phosphorus in the lake sediments, and ii) the impacts of fertilization on the longer-lived fish species, especially the game fish. These two subjects are discussed below.

Sediment P - release rates: The Las Vegas Valley Water District (LVVWD) has expressed the concern that fertilizer phosphorus which ultimately sediments out of the water column could accumulate and, under certain conditions, could be released to the overlying water at a later time. This theoretical scenario was taken to represent a potential long-term cumulative effect.

We have addressed this concern in three ways:

1) The calculations in Table 4 present worst case scenarios for the potential phosphorus load at the Hoover Dam discharge from Lake Mead which is also near the LVVWD domestic water intake at Saddle Island. These calculations clearly show that there is virtually no potential for the proposed Overton Arm experiment to produce a measurable effect on phosphorus levels in Boulder Basin. It should further be noted that these calculations

assume that none of the fertilizer-P is sedimented.

2) Although it is not possible to accurately predict the actual sedimentation and potential "re-release" of phosphorus to overlying water directly resulting from the Overton Arm Fertilization, it is possible to provide a worst-case estimate.

Sediment release rates for Bonelli Bay (in Virgin Basin) and the Inner Las Vegas Bay were estimated by Dr. J. Murray (17) for the 1980-1982 Las Vegas Bay Water Quality Standards Study. We have assumed the following

a) The Inner Las Vegas Bay rate (1.3 $mgP/m^2/day$) was used to estimate sediment P-release from Boulder Basin and Las Vegas Bay (due to relatively high historical P-loading from domestic wastewater discharges from Las Vegas Wash).

b) The Inner Las Vegas Bay rate (1.3 $mgP/m^2/day$) was used as an estimate of the maximum potential release from the Overton Arm Fertilization region.

c) The Bonelli Bay rate (0.066 $mgP/m^2/day$) was used to estimate P-release from all other areas of Lake Mead.

Based upon the above assumptions we have calculated a maximum additional release of phosphorus to the overlying water (the entire lake volume) of 0.0032 $mgP/m^3/day$ (3 parts-per-trillion of P per day). This daily concentration increase is more than 100 times lower than the analytical detection limit for phosphorus.

3) In certain situations in some aquatic ecosystems, it is clear that the release of phosphorus from sediments can be important. However, in virtually all lakes, and especially in systems strongly influenced by inorganic turbidity (silt), such as Lake Mead, much of the sediment phosphorus

becomes permanently buried. This pool is therefore not a potential source of phosphorus for algal growth in overlying waters.

Fisheries: The major impacts of the proposed 1988 and 1989 fertilizations on fish populations would be relatively short- term, occurring during the years of fertilizer application. A carry-over effect would occur, for example, if an increase in shad production were to enhance largemouth bass survival during their first winter (see Appendix 1, Section IV). Similarly, an increase in the forage base of striped bass during one year would be expected to affect body size and possibly fecundity in the following year. These "cascading" effects, although beneficial, would not, however, be prolonged for more than a few years (at most) if artificial fertilization were not continued (as is the case with the proposed research). The cumulative effects of a long-term program of artificial fertilization would depend on many factors, but could probably be influenced in a management-oriented program by judicious use in the timing and extent of fertilizer application. The proposed research and this EA do not, however, address a long-term program of nutrient enhancement.

7. LIST OF PREPARERS

This EA was prepared by the following persons from the Lake Mead Limnological Research Center (LMLRC) of the University of Nevada-Las Vegas: Dr. Larry Paulson (Director, LMLRC), Dr. Richard Axler (former Assistant Director, LMLRC; currently Research Limnologist at the Natural Resources Research Institute - Center for Water and the Environment, University of Minnesota - Duluth, Duluth, MN 55811), and Dr. Peter Vaux (Assistant Director, LMLRC). Preparation of the EA was undertaken in consultation with the Lake Mead Nutrient Enhancement Technical Committee (LMNETC) and followed a scoping meeting convened by NPS on 18 March, 1988 (see Appendix 5 for list of attendees).

8. CONSULTATION AND COORDINATION (List of persons and agencies consulted)

The need for a program to evaluate large-scale controlled nutrient additions for managing the fisheries in Lake Mead has developed since about 1980. Since then, numerous individuals, private citizens groups, academic scientists, environmental consultants and responsible governmental agencies have provided valuable discussions regarding desirability, design and implementation, and potential impacts of the project. The research program designed for the proposed 1988 and 1989 experimental fertilizations has been peer-reviewed by a series of scientists with experience in fisheries biology, limnology and natural resources management. A list of their names is available upon request.

The following list includes organizations and persons consulted during the planning of the proposed research.

Federal Agencies

U.S. Bureau of Reclamation

U.S. Environmental Protection Agency

National Park Service

U.S. Fish and Wildlife Service (including Endangered Species Office, Reno, Nevada)

Canadian Department of Fisheries and Oceans - Salmonid Enhancement Program

State/Regional Agencies

Nevada Division of Environmental Protection

Nevada Department of Wildlife

Arizona Game and Fish Department

Alaska Fish and Game - Fisheries Rehabilitation and Enhancement Program

Colorado River Board of California

Colorado River Commission of Nevada

Metropolitan Water District of Southern California

California State Attorney General's Office

Colorado River Basin Salinity Control Forum

Local Agencies

Las Vegas Valley Water District

Clark County Sanitation District

City of Las Vegas Sewage Treatment Plant

Clark County Health Department

University Scientists

Dr. Larry Paulson, Director, Lake Mead Limnological Research Center, University of Nevada-Las Vegas

Dr. Richard Axler, Assistant Director, Lake Mead Limnological Research Center, University of Nevada-Las Vegas

Dr. Peter Vaux, Assistant Director, Lake Mead Limnological Research Center, University of Nevada-Las Vegas

Dr. Donald Baepler, Director, Museum of Natural History, University of Nevada-Las Vegas

Dr. Richard Gersberg, Department of Occupational and Public Health, San Diego State University

Dr. John Reuter, Division of Environmental Studies, University of California-Davis

Dr. Charles Goldman, Director, Tahoe Research Group, Division of Environmental Studies, University of California-Davis

Dr. James Deacon, Biology Department, University of Nevada-Las Vegas

Dr. Wayne Wurtsbaugh, Department of Fisheries and Wildlife, Utah State University, Logan, Utah

Dr. Peter Moyle, Department of Wildlife and Fisheries, University of California-Davis

Dr. Charles Coutant, Environmental Sciences Division Oak Ridge National Laboratory

Dr. Bruce Kimmel, Environmental Science Division, Oak Ridge National Laboratory

Dr. William Matthews, University of Oklahoma Biological Station

Dr. Paul Turner, University of New Mexico

Dr. Joe Campana, Environmental Research Center, University of Nevada-Las Vegas

Dr. Mahmoud Saleh, Environmental Research Center, University of Nevada-Las Vegas

Dr. Klaus Stetzenbach, Environmental Research Center, University of Nevada-Las Vegas

Dr. Steven Paulsen, Environmental Research Center, University of Nevada-Las Vegas

Scientists Requested by NPS to Review the January 1988 Proposal

Associate Regional Director, Resource Management and Planning, Western Region, National Park Service

J.D. Varley, Chief of Research, Yellowstone National Park

L. Marnell, Aquatic Ecologist, Glacier National Park

D. Graber, Research Scientist, Sequoia and Kings Canyon National Parks

G.L. Larson, Cooperative Park Studies Unit, College of Forestry, Oregon State University Corvallis

R. Wasem, Management Biologist, North Cascades National Park

Environmental Engineering and Consulting Firms

Mr. John Baker, Lockheed Environmental Management and Services Company, Las Vegas, NV

Businesses and Organizations

Lake Mead Fishing Enhancement Society

U.S. Bass

West Coast Bass

Operation Bass, Inc.

Bass Research Foundation

National Striper Association

Silver State Bassmasters

Nevada Striper

Las Vegas Bass Club

Southern Nevada Bassmasters

Las Vegas Fly Fishing Club

Local Professional Fishing Guides

Las Vegas News Bureau

Las Vegas Review Journal (local newspaper)

Las Vegas Sun (local newspaper)

Chaparral Fishing Club

9. LITERATURE CITATIONS AND NOTES

Where full literature citations do not appear, they are fully referenced in Appendix 1, Section VI, of this EA.

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APPENDIX 1

Proposal submitted to the National Park Service for the 1988 Lake Mead Fertilization Research Program, January 1988.

(Note: The proposed 1989 research program would largely follow the design of the 1988 program, although minor modifications could be made following analysis of the 1988 data base.)

The Proposed 1988 Lake Mead Fertilization Project

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University of Nevada, Las Vegas

In Cooperation with

Lake Mead Nutrient Enhancement Technical Committee

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EXECUTIVE SUMMARY

Major changes have occurred in the Lake Mead fisheries over the past two decades. The once famous largemouth bass (Micropterus salmoides) fishery began to decline in the late 1960s following the construction of Glen Canyon Dam in 1963, 456 km upstream. Striped bass (Morone saxatilis) and salmonids, primarily rainbow trout (Salmo gairdnerii) were introduced in 1969 to supplement the failing bass fishery. Threadfin shad (Dorosoma petenense), the main forage base in Lake Mead, were abundant in epilimnetic waters at that time, particularly in the lower basin (Las Vegas Bay and Boulder Basin). Trout and adult striped bass, which have to occupy deeper waters in limnetic areas during summer because of their temperature requirements, were able to migrate to the epilimnion and feed on shad. These fisheries flourished during the early and mid-1970s, respectively.

The trout fishery collapsed after 1976. Condition factors of striped bass began declining after 1979 and by the early 1980s emaciated stripers were prominent in the population. The largemouth bass fishery continued its decline during the 1970s. The fisheries problems in Lake Mead have generated a lot of concern from sportsmen. Numerous fisheries and limnological studies have been conducted in the past decade. The lack of forage in limnetic areas seems to be the major problem in Lake Mead. Shad abundance decreased considerably in Boulder Basin after 1975. This closely paralleled a decrease in phytoplankton productivity that occurred in the basin due to reductions in phosphorus loading from tertiary treatment of wastewaters. A similar decline in productivity occurred in the upper basin (above Boulder Canyon) after 1963 when Glen Canyon Dam was constructed upstream and cut off the phosphorus-rich sediments in the Colorado River.

Most of Lake Mead is now oligotrophic. The limnetic areas are very low in phosphorus and productivity, and are virtually devoid of plankton and shad. The inflow areas are the only locations in Lake Mead where algal productivity is apparently high enough to sustain zooplankton production at levels resulting in moderate to high shad densities. These areas comprise a small percentage of the surface area of Lake Mead.

Productivity in Lake Mead will remain low unless measures are taken to improve the fertility. Some additional phosphorus may be routed through Lake Powell now that it is full, but that reservoir will continue to retain most of the phosphorus in the Colorado River. Recent proposals have been made to relax phosphorus standards on Las Vegas wastewater discharges during winter. That will help improve fertility in the lower basin but will have no effect on the upper basin.

The Nevada Department of Wildlife and Arizona Game and Fish Department recommended in 1982 that large scale fertilization be evaluated as a means of improving fertility in the upper basin. The Lake Mead Nutrient Enhancement Technical Committee (LMNETC), which is comprised of biologists from state and federal agencies, was formed in 1984 to develop plans for a large scale test fertilization. Small-scale pilot tests were conducted in Overton Arm in 1986 to select the most suitable fertilizer and develop procedures for its application. An Environmental Assessment was completed for a 20,000 acre test in the Overton Arm in March 1987. The National Park Service (NPS) issued a FONSI for the project in May 1987. A NPDES permit was subsequently issued by the Nevada Division of Environmental Protection. An Incident Command System was established by NPS to organize the massive effort.

On May 30. 1987, 1000 volunteers in 300 boats added 20,000 gallons of liquid ammonium polyphosphate fertilizer (10-34-0) to about 20,000 acres of the Overton Arm. Intensive monitoring showed that the fertilizer quickly mixed to a depth of about 10 m across the test area. Nutrients were rapidly assimilated by phytoplankton, and chlorophyll-a increased to moderate levels in a few days. The nutritional state, reproductive rates and densities of zooplankton increased a few days later. Echosounding and mid-water trawling indicated that shad abundance was higher in the fertilized area than it was in control areas or historically in the Overton Arm. Large schools of striped bass were observed surface feeding on shad by late July, and "top water" fishing was excellent during summer and fall. Striped bass condition factors increased by about 20% over historical levels for that area and 28% relative to all other combined areas of the lake since 1984.

Data are currently not available to evaluate the effects on the largemouth bass fishery.

There were no adverse impacts to water quality in Lake Mead. The fertilizer was confined largely in the test region. It did not affect the salinity or pH of the water. No nuisance algae blooms or odors were evident, nor did periphyton growth increase on hulls of moored boats. There were no adverse effects on other recreational uses or on municipal water users downstream. The project was a huge success and received favorable press from outdoor writers throughout the country.

The research program outlined in this proposal is a logical next step of the 1987 project. We propose to enlist volunteers again to add 15,000 gallons of liquid ammonium polyphosphate fertilizer to about 20,000 acres in the Overton Arm in late May, 1988 followed by another application of 5,000 gallons in late June. Our main objective is to further improve shad production by sustaining a moderate level of productivity into the early summer when some shad are still spawning.

We also plan to add up to 5,000 gallons of liquid fertilizer to select coves by barges during late summer. This is designed to increase food resources available to shad when they occupy littoral areas during the fall. This should help sustain growth and condition of largemouth bass and thus improve their overwinter survival.

Intensive limnological monitoring will be conducted in the

Overton Arm throughout the year to evaluate the effects of each fertilization on phytoplankton and zooplankton production. Extensive echosounding, mid-water trawling and electrofishing will be used to evaluate the response of shad and gamefish to the fertilization.

The proposed 1988 fertilization is the second year of a three year experimental program. This research is a vital link in our continuing efforts to evaluate artificial fertilization as a potential management tool for improving the forage base and quality of the Lake Mead fisheries.

THE LAKE MEAD FOOD CHAIN

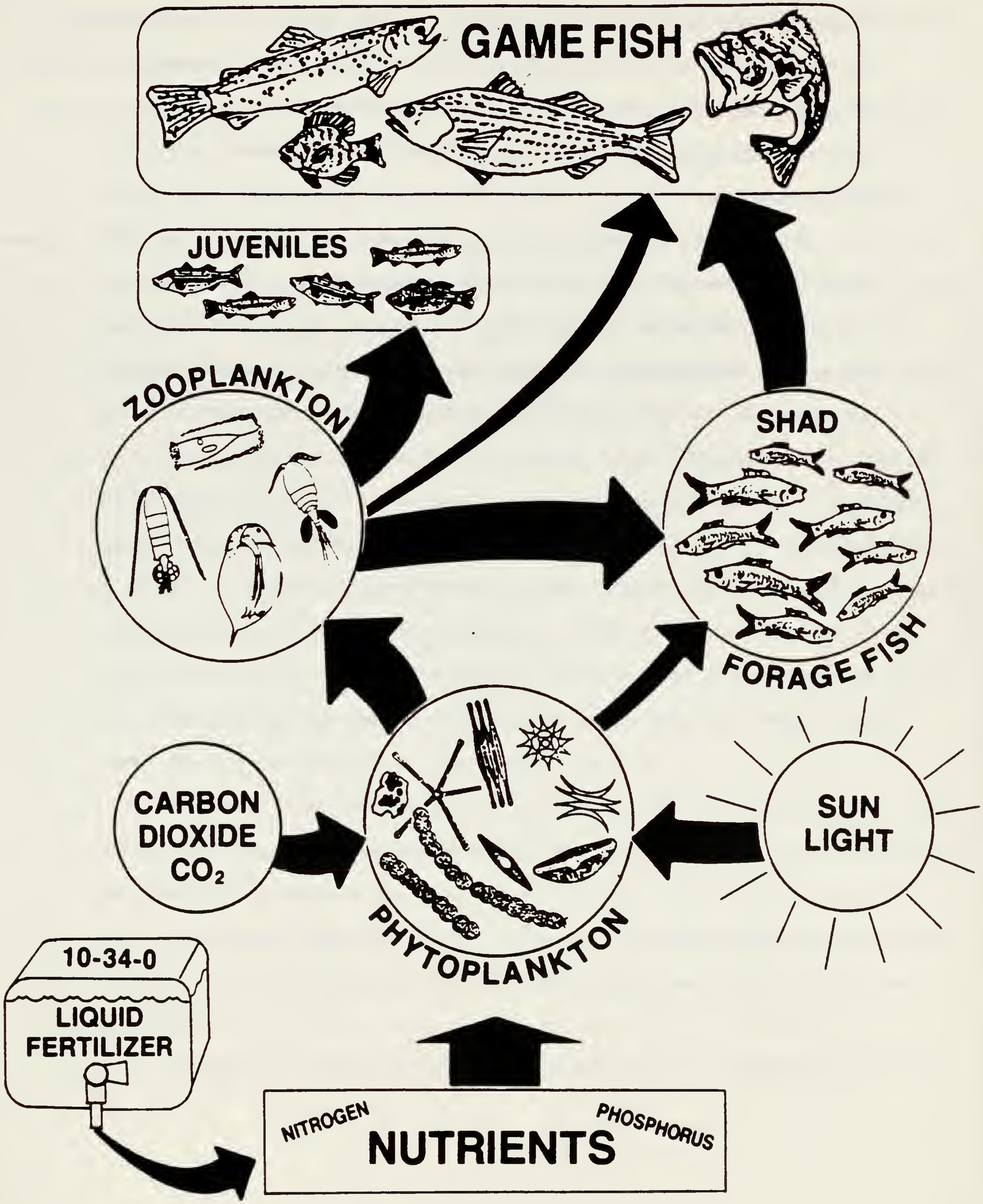


Illustration 1

I. INTRODUCTION

A. History of the Lake Mead Fisheries

Largemouth bass (Micropterus salmoides) were first stocked in Lake Mead during 1935, shortly after impoundment of the Colorado River by construction of Hoover (Boulder) Dam (Wallis 1951). The bass population exploded during the late 1930s, and Lake Mead became known throughout the country for its "fabulous" bass fishing. In early spring of 1941, however, fishermen complained that the fishery was declining and that the bass were "thin and had lost their gameness" (Moffett 1943). Moffet's study revealed that vegetation in Lake Mead was sparse and, "plankton was none too plentiful". The condition of bass improved again following high spring runoff in 1941, and the fishery remained good through the late 1940s (Hoffman and Jonez 1973).

Another slump in the bass fishery occurred in 1950 (Hoffman and Jonez 1973). Subsequent studies by the Nevada Department of Fish and Game (Jonez and Sumner 1954) demonstrated that the lack of habitat (cover) and forage were the principal causes for problems with the fishery. Numerous alternatives, including artificial fertilization, were evaluated for improving the fisheries. Threadfin shad (Dorosoma petenense) were introduced in 1954-55, and they significantly increased growth rates of subadult bass (Minckley 1972). Age 0 bass averaged 136 mm (TL) prior to the shad introduction compared to 240 mm (TL) after they became established in the reservoir. Age I bass increased from an average size of 261 mm (TL) to 316 mm (TL) over the same period. Fishery success also improved following the high runoff years of 1955, 1957, 1958 and 1962. The annual harvest reached an all-time high of ~800,000 in 1963 (Hoffman and Jonez 1973, Morgenson and Padilla 1982, Figure 1).

The bass fishery began another decline after 1963 when Lake Powell was impounded 456 km upstream by construction of Glen Canyon Dam. The annual harvest of largemouth bass decreased to about 400,000 by the late 1960s (Morgenson and Padilla 1982). Upstream regulation of the river by Glen Canyon Dam changed the hydrologic regime in Lake Mead from one of rising water levels during spring, to 2-3 m drawdowns (Hoffman and Jonez 1973). The decline of the fishery was attributed primarily to a decrease in bass spawning success as a result of these spring drawdowns (Hoffman and Jonez 1973, Romero and Allan 1975).

The filling criteria for Lake Powell established by the Department of Interior did not allow for manipulations of water levels to better accommodate bass spawning in Lake Mead. Fisheries biologists subsequently recommended that limnetic predators, whose ecology was less influenced by water level fluctuations, be introduced into the lake. Striped bass (Morone saxatilis) and salmonids, mainly rainbow trout (Salmo gairdnerii) were introduced during 1969 to augment the failing bass fishery.

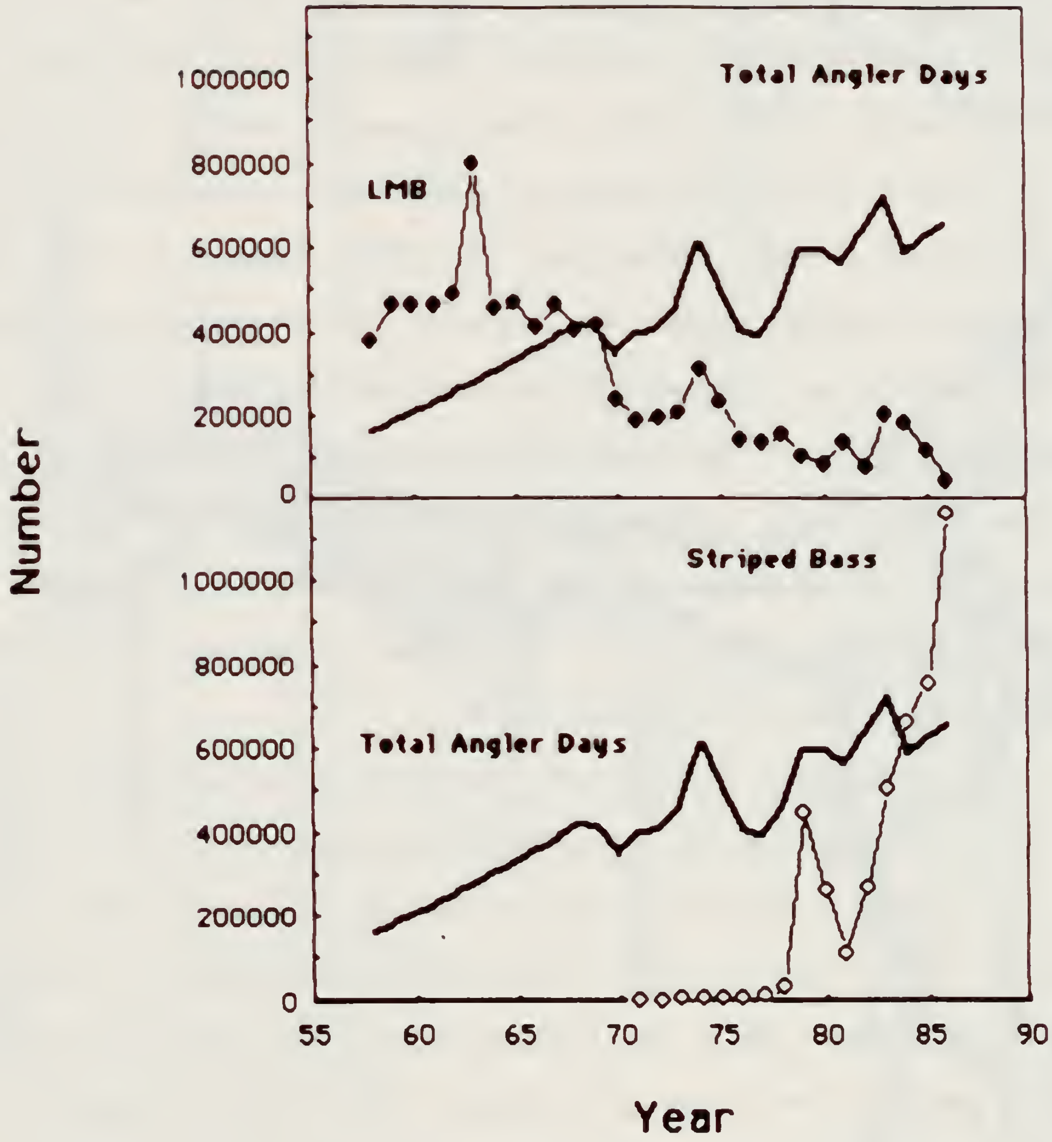


Figure 1 . Summary of creel census data for largemouth bass (LMB), striped bass, and total angler days for Lake Mead as compiled by the Nevada Department of Wildlife and Arizona Game and Fish Department. Values plotted for 1958-1984 from data tabulated in the NDOW Federal Aid Job Completion Reports for 1984, 1985 and 1986 (F-20,21,22) and compiled by J.Hutchings of NDOW.

At that time, threadfin shad were abundant in Lake Mead, particularly in the lower basin downstream of Boulder Canyon (Figure 2) (Deacon et al. 1972, Allan and Roden 1978) where phytoplankton productivity was higher due to discharges of secondary-treated wastewaters from Las Vegas Wash (Everett 1972). Age I and Age II shad were prevalent in littoral areas during late winter and spring (Deacon et al. 1972) They spawned during late May and early June and large schools of juveniles dispersed into limnetic areas during summer (Deacon et al. 1972, Deacon and Tew 1973). Although juveniles comprised most of the limnetic population, adults were also frequently captured in mid-water trawls (Allan and Roden 1978). The shad occurred primarily in the epilimnion and metalimnion to depths of 15-20 m (Paulson and Espinosa 1975, Figure 3). They dispersed to deeper waters at the onset of fall mixing (Deacon and Tew 1973) and large schools overwintered in the deep basins (Allan and Roden 1978).

The abundance of shad in limnetic areas was ideal for trout and adult striped bass. Trout in Lake Mead occupied depths of 30-40 m at temperatures of 13-15 °C during summer (Allan and Roden 1978). Trout captured at those depths had shad in their stomachs (Allan and Roden 1978) indicating they were periodically ascending to the epilimnion to feed on shad. Adult striped bass prefer temperatures between 18-25 °C (Cox and Coutant 1981, Coutant 1986, and they are forced into limnetic areas at depths of 15-25 m in order to satisfy their temperature requirements (Paulson and Baker

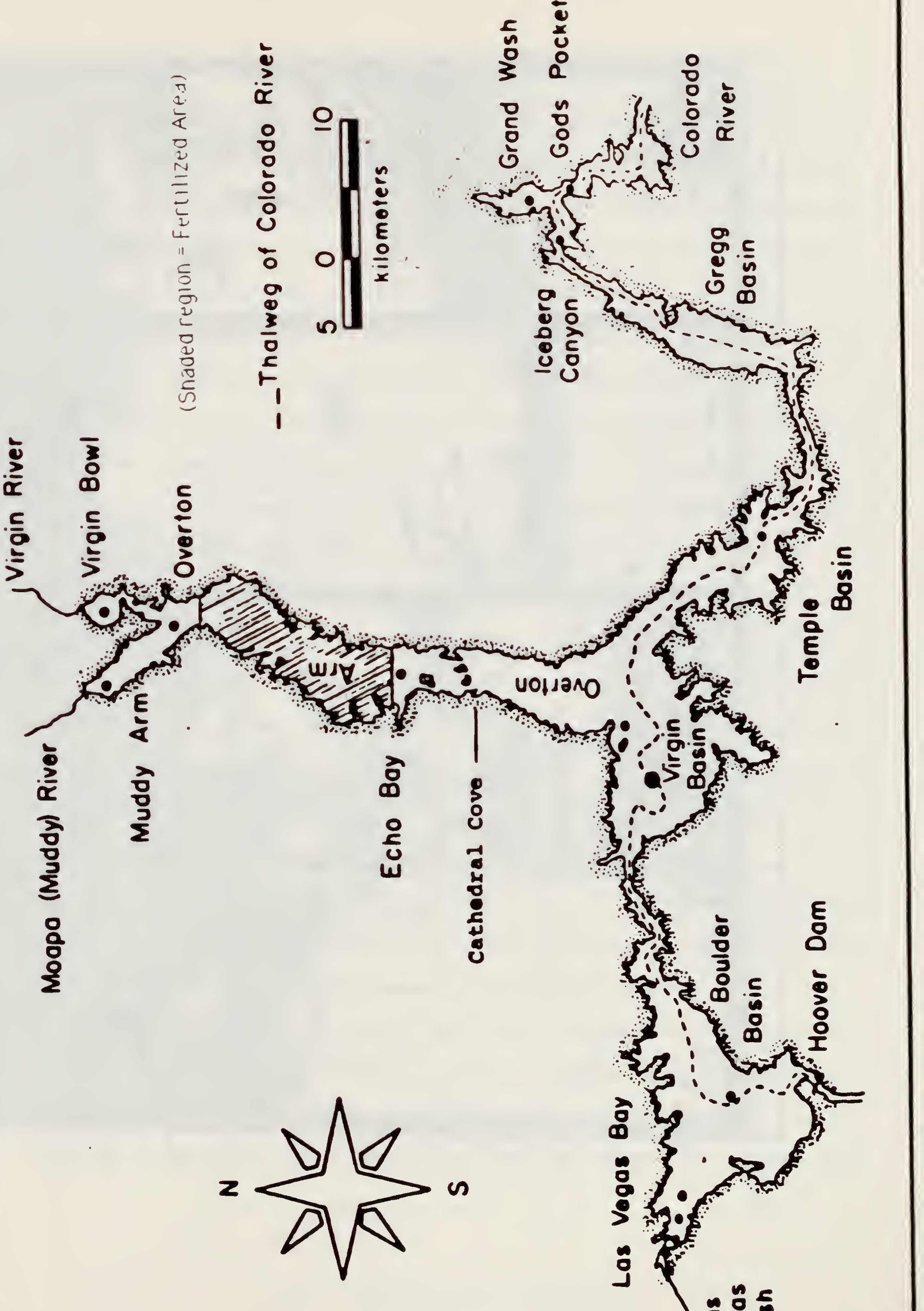


Figure 2. Lake Mead

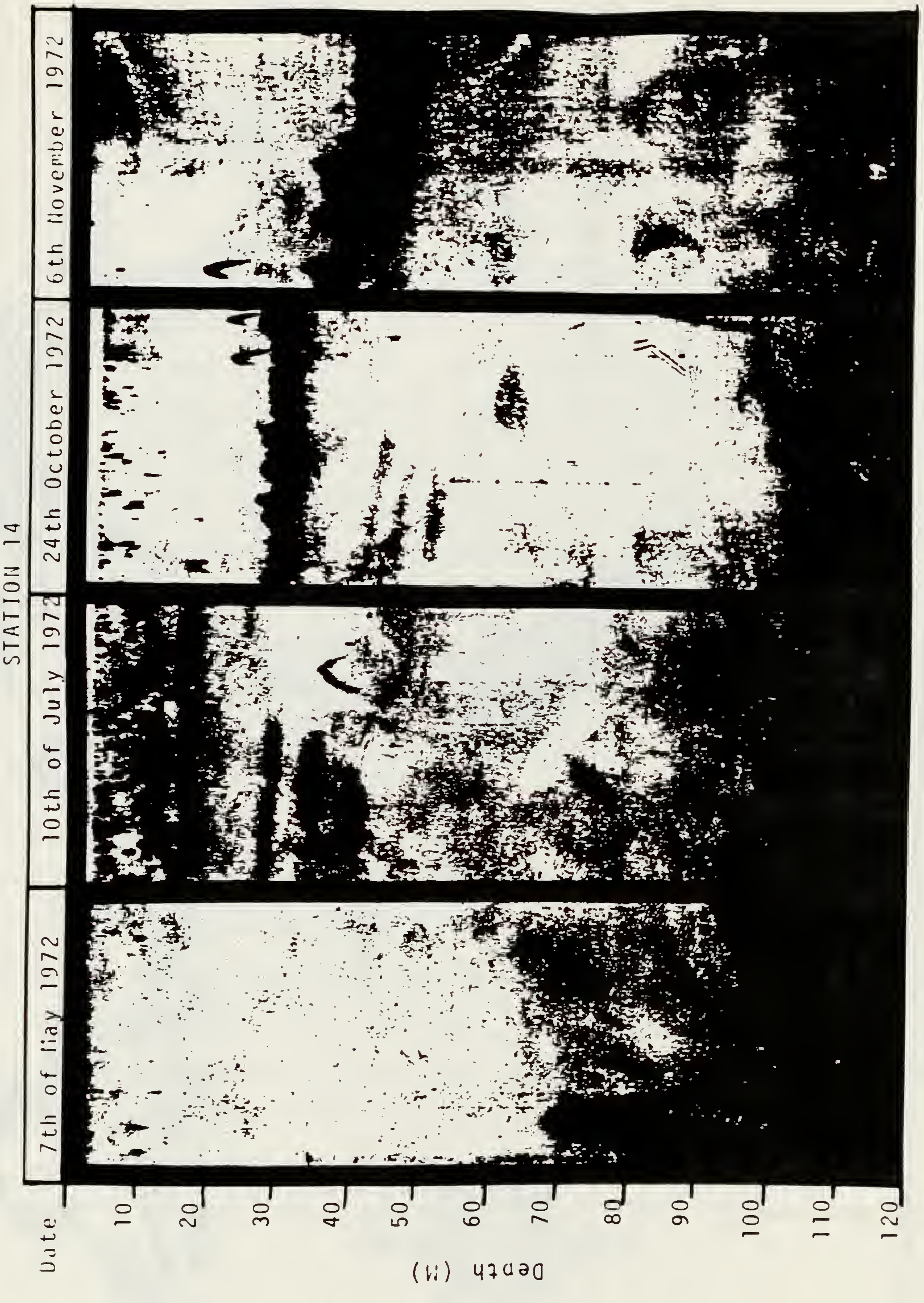


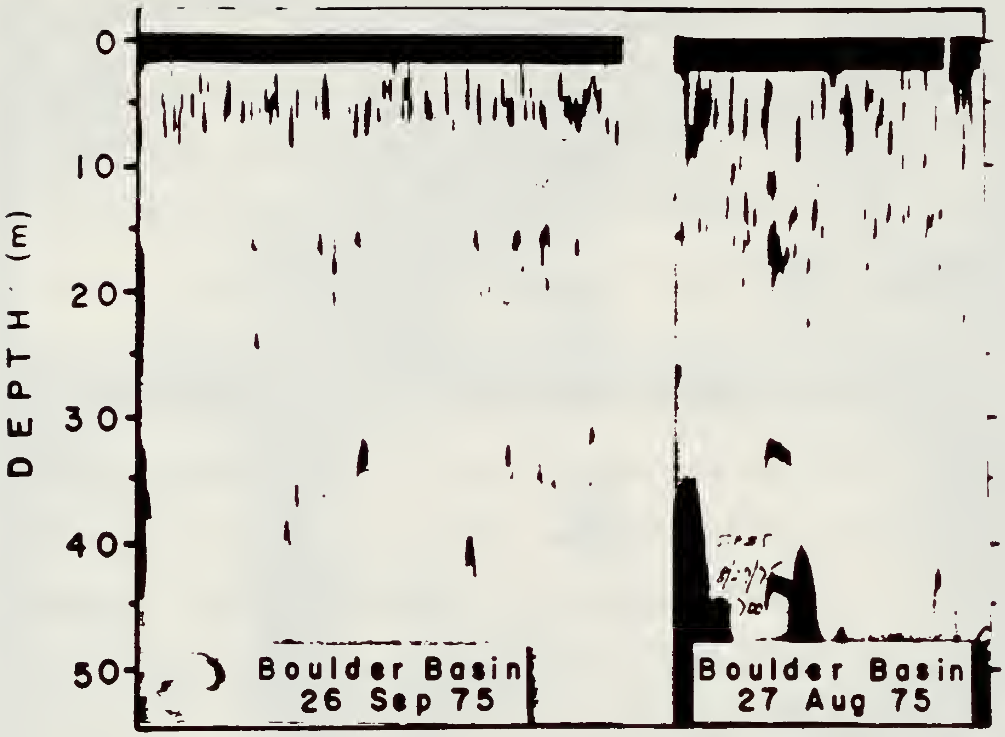
Figure 3. Echograms from Boulder Basin in 1972 (from Deacon and Tew 1972)

1983a). Their distribution patterns overlapped more closely with shad than those for trout, but they too had to make brief migrations to the epilimnion to feed on shad. This phenomenon was well known to striped bass fishermen who referred to these feeding migrations as "striper boils".

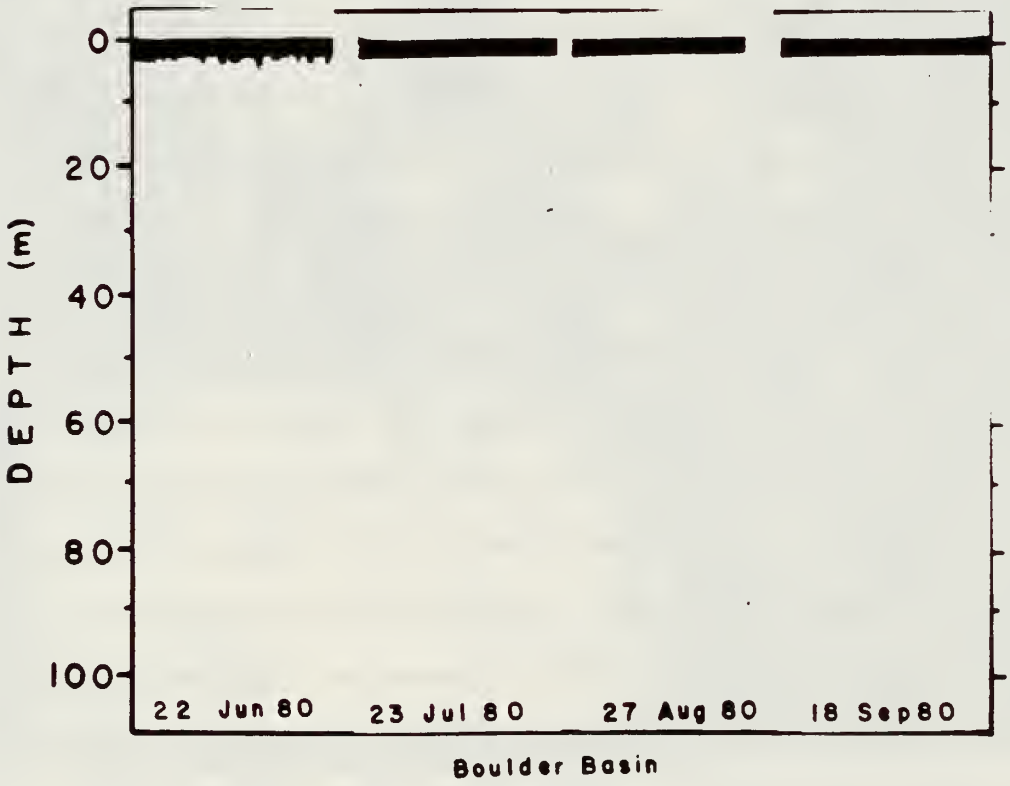
The trout fishery, which was maintained by frequent stocking, flourished during the early 1970s. Striped bass successfully reproduced in 1973, and the population rapidly expanded during the mid-1970s. Anglers frequently caught 5-10 lb. rainbow trout and 15-20 lb. striped bass during the mid-1970s (NDOW 1985a). Most of these fish were caught in the lower basin.

The trout fishery collapsed after 1976 and did not recover despite continued high stocking during the late 1970s (Morgenson and Padilla 1982). Many fishermen believed predation by striped bass was the problem since trout frequently occurred in diets of large adult stripers (Allan and Roden 1978). Predation was probably a factor, but it is unlikely it was the sole cause for the collapse of the trout fishery.

The shad population in the lower basin of Lake Mead declined drastically between 1975 and 1980 (Baker and Paulson 1983, Figure 4). As shad densities decreased, trout were no doubt forced to spend more and more time foraging in the epilimnion where temperatures exceeded their thermal tolerance. Mortality induced by thermal stress and outright starvation were probably more significant factors in the sudden collapse of the trout fishery than



Echograms form Boulder Basin, 1975.



Echograms from Boulder Basin, 1980.

Figure 4 . Boulder Basin Echograms (from Baker and Paulson 1983) predation by striped bass.

The striped bass population itself began experiencing serious problems during the late 1970s and early 1980s. Condition factors of adult stripers decreased considerably after 1977 and by 1980 severely emaciated individuals were common in the population (Baker and Paulson 1983, Figure 5). Summer dieoffs of adult striped bass were frequently observed in the reservoir by 1978 and 1979, and large stripers became rare in the angler's catch (NDOW 1985a). Similar dieoffs have been observed in other reservoirs, and are thought to be due to low oxygen concentrations (< 2 mg/l) in the thermal refuges of adult striped bass (Coutant 1984). A negative heterograde oxygen curve develops in the metalimnion of Lake Mead (Paulson et al. 1980), but oxygen concentrations rarely drop below 4 mg/l in most of the reservoir (Paulson and Baker 1983a). There is no shortage of suitable, well oxygenated thermal habitat for adult striped bass in Lake Mead. The problem is that forage is now lacking in most limnetic areas.

Shad are still numerous near the productive inflow areas of the Virgin, Muddy and Colorado rivers, and they are extremely abundant in the inner and middle Las Vegas Bay (Paulson and Baker 1983a, Wilde 1984, Figure 6). Adult striped bass are excluded from the inner bay during late summer by high temperatures (Paulson and Baker, in press). Suitable thermal habitat exists in the metalimnion in the middle Las Vegas bay. Metalimnetic oxygen concentrations frequently decrease below the critical level of 2

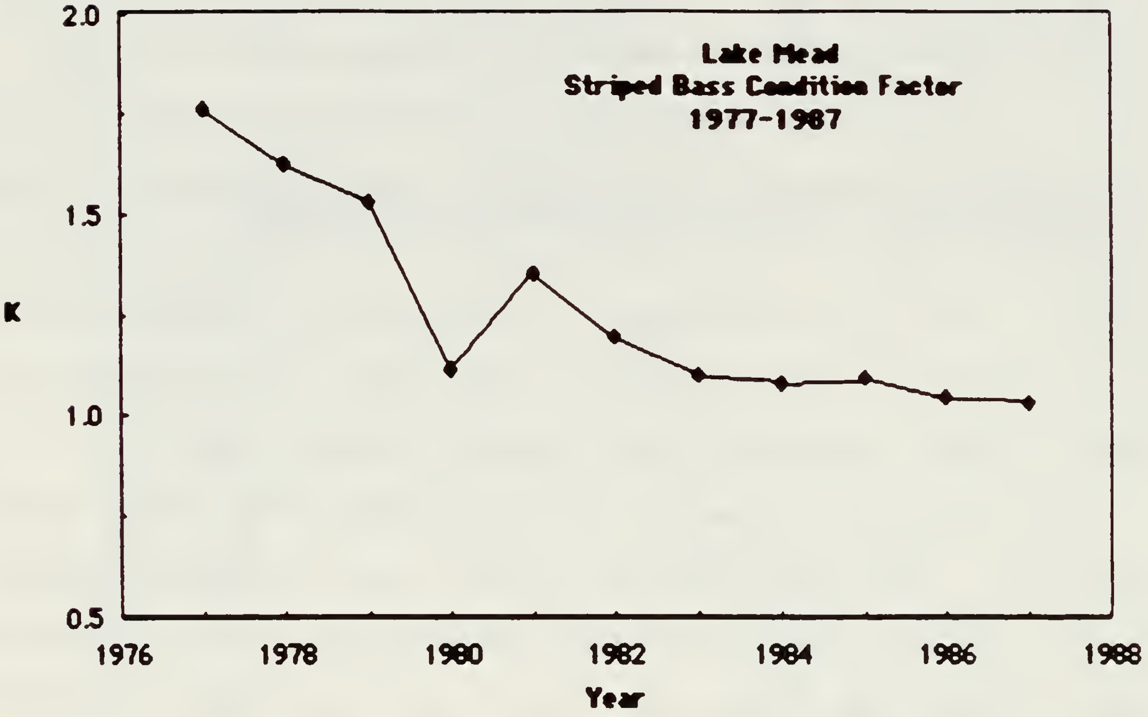


Figure 5. Striped bass condition factors for Lake Mead. Values were calculated from creel census records as $k = (\text{weight} \times 10^5)/\text{forklength}^3$, where weight is in grams and forklength is in mm. Data for 1977 to 1986 compiled from Nevada Department of Wildlife published reports (NDOW 1983, 1984 and 1986). 1987 data are for 1161 fish from January-July, only, and were provided by J. Hutchings, NDOW, Las Vegas, NV.

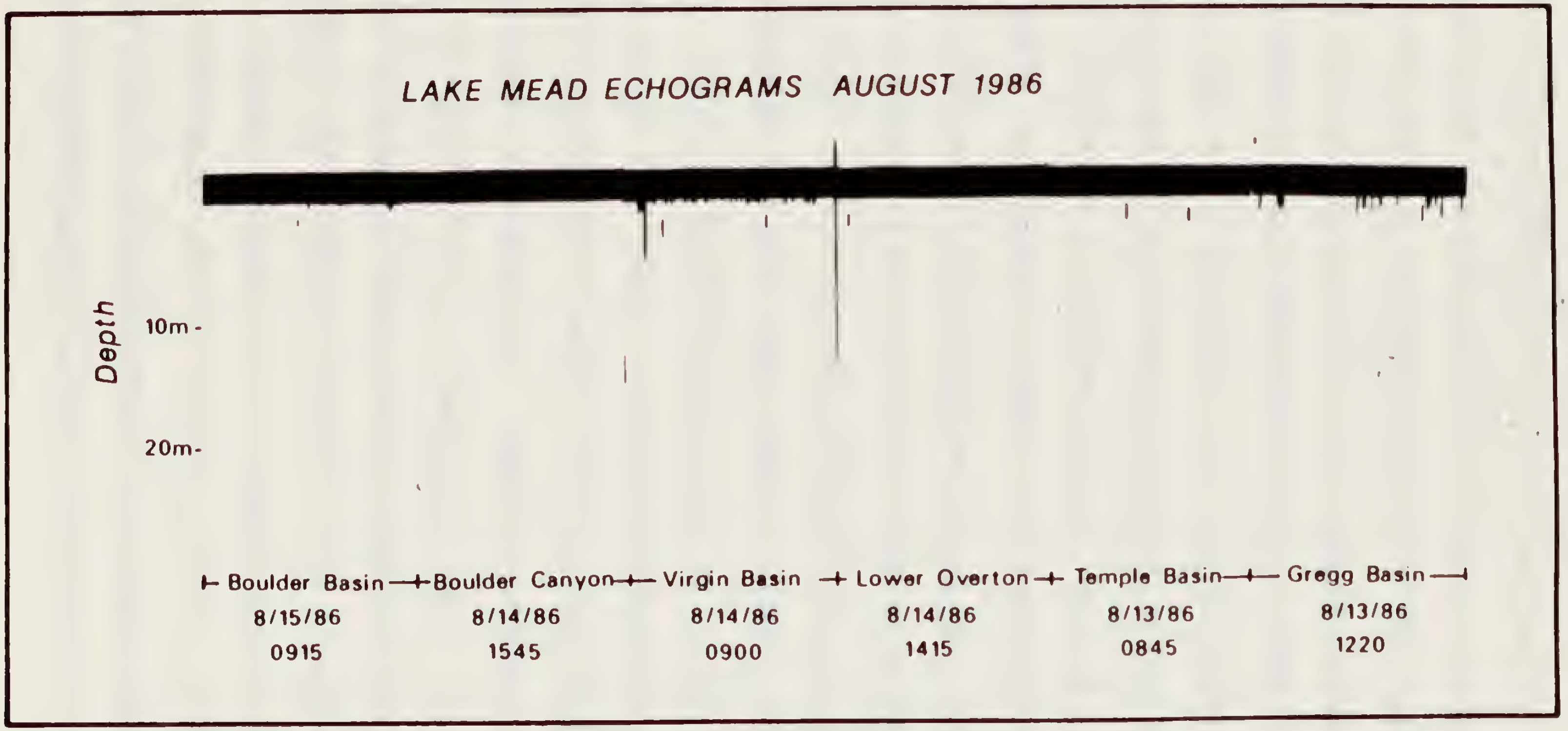


Figure 6. Lake Mead echograms (main basins) for midsummer 1986.

mg/l (Coutant 1986) during summer, and striped bass are forced farther into the bay where shad densities are lower (Paulson and Baker in press). Adult striped bass are thus caught in a temperature-oxygen-forage "squeeze" in Lake Mead, and few of them reach the large sizes that once were typical of the population.

Catch rates for striped bass have increased considerably in recent years (Figure 1), but the fish are small and usually in poor condition (Figure 5 and see Figure 22). Reproduction is adequate to sustain large numbers of subadults in the population. Juvenile shad are the preferred forage for subadults (Albert and Baker 1983). Shad are particularly vulnerable to predation by subadults because their distributions overlap. Subadults can occupy reservoir depths where temperatures range from 20-24 •C (Coutant and Carroll 1980), and they can tolerate temperatures as high as 28-30 •C with minimal effects on their feeding or growth rates (Cox and Coutant 1981). Subadults can utilize the epilimnion and productive inflow areas where shad densities are highest (Paulson and Baker 1983a). This results in tremendous pressure on the remaining shad population. The productive inflow areas seem to be the only location where shad production is sufficient to sustain cropping by subadults. Lake-wide, however, the shad population is maintained at low levels because the inflow areas comprise such a small percentage of the surface area of Lake Mead.

The decrease in the shad population also seems to have resulted in further declines in the largemouth bass fishery. Few largemouth bass over 5 lbs have been reported in NDOW's Trophy Fish Program since the early 1970s (NDOW 1985a). The annual catch has decreased from about 200,000 in 1970 to ~100,000 in 1980 and about 50,000 in recent years (Figure 1). Extensive studies conducted by the Nevada Department of Wildlife (NDOW) and the Arizona Game and Fish Department (AGFD) during 1977-1981 once again demonstrated that lack of cover and forage were the major problems with the largemouth bass fishery (Morgenson and Padilla 1982). First year survival of bass in Lake Mead is low by comparison to other reservoirs (Morgenson 1983). The problem seems to stem from low availability of suitable sized forage during the critical, mid-summer transition to a fish diet (Aggas and Elliott 1975). Bass which cannot shift to a fish diet, either because of low densities or large sizes of forage, suffer high initial mortality during summer (Wicker and Johnson 1987) or reduced growth during summer (Shelton et al. 1979, Timmons and Shelton 1981) which reduces their chances of survival over winter (Moyle and Holtzhauser 1978, Davies et al. 1982) and limits recruitment in the population (Gutreuter and Anderson 1985).

Juvenile largemouth bass in Lake Mead utilize primarily aquatic insects and zooplankton until they reach 40 mm (TL) and shift almost exclusively to a fish diet once they reach 60-70 mm (TL) (Allan and Roden 1978). Shad spawn during late May and early June and are usually 20-30 mm (TL) by summer (Deacon et al. 1972). Young-of-year shad were extremely abundant in limnetic areas during summer in the early 1970s and were extensively utilized by bass during the summer and fall (Deacon et al. 1972). Growth rates of Age 0 and Age I bass increased significantly after shad were introduced in 1954-55 (Minckley, 1972). Shad densities are now low in most open-water areas of Lake Mead during the summer (Figures 4 and 6, see also Figures 20b and 21c). Juvenile bass are forced to stay on zooplankton and insect diets, neither of which seem adequate to sustain growth and condition at levels necessary for good over-winter survival.

B. Relationship of the Fisheries to Productivity in Lake Mead

Fish yield in lakes and reservoirs is directly related to levels of phytoplankton standing crop (Jones and Hoyer 1982) and productivity (Schaefer 1965, Melack 1976, Ogelsby 1977, Hecky et al. 1981). Such seems to be the case in Lake Mead where historical changes in the shad population closely parallel changes in productivity.

The correlation between the magnitude of spring runoff and success of the bass fishery was noted early in the history of Lake Mead (Jonez and Sumner 1954). Nitrogen and suspended sediment loading in the Colorado River inflow to Lake Mead varied in relation to spring runoff until 1963 (Paulson and Baker 1981). Operations of Glen Canyon Dam reduced the magnitude of spring runoff and cut off the phosphorus-rich sediments (Mayer and Gloss 1980) that historically enriched the upper basin of Lake Mead (Prentki and Paulson 1983). Lake Powell retains up to 90% of the phosphorus in the Colorado River (Gloss et al. 1981, Evans and Paulson 1983). This upstream reduction in phosphorus loading was accompanied by a significant decrease (up to 80%) in productivity in the upper basin of Lake Mead (Prentki et al. 1981, Prentki and Paulson 1983).

The first direct measurements of phytoplankton productivity were made in Lake Mead during 1970-71 (Everett 1972). Productivity in the upper basin at that time ranged from 200-400 mgC/m^2/day during spring and summer and up to 2000-3000 mgC/m^2/day during early fall. Similar levels of productivity were measured in the upper basin during spring and summer of 1978 and 1981, but rates were much lower during early fall (Paulson et al. 1980, Paulson and Baker 1983a).

Productivity in the lower basin (Las Vegas Bay and Boulder Basin) was much higher than the upper basin and ranged from 700-1200 mgC/m^2/day during spring and summer up to 3000-32000 mgC/m^2/day during early fall of 1970-71 (Everett 1972). Water quality surveys conducted in Lake Mead during the late 1960s and early 1970s documented high phytoplankton densities in Las Vegas Bay as a result of high phosphorus loading from wastewater discharges in Las Vegas Wash (USDI 1967, 1970; Hoffman et al. 1971). EPA (1971) recommended that measures be taken to control phytoplankton growth and protect the bay from further degradation.

The Nevada Environmental Commission (NEC) adopted a 0.5 mg/l phosphorus standard in Las Vegas Wash in 1973. Clark County (CC) immediately began planning for construction of an advanced wastewater treatment (AWT) plant to meet the standard. The phosphorus standard was later relaxed to 1 mg/l as a result of a lawsuit by the City of Las Vegas (CLV). CC began construction of the AWT plant in 1977.

Phosphorus loading in Las Vegas Wash began decreasing in the late 1970s and dropped drastically in 1981 when full-scale tertiary treatment was started by the CLV and CC (Paulson and Baker in press). Productivity in the inner and middle Las Vegas Bay was largely unaffected by decreased phosphorus loading, but it decreased significantly in Boulder Basin during the late 1970s and early 1980s (Paulson and Baker 1983a, Paulson and Baker in press). Phytoplankton standing crop as measured by chlorophyll-a showed a similar trend (Paulson and Baker in press).

Zooplankton densities in Lake Mead are strongly influenced by levels of chlorophyll-a and productivity (Wilde 1984, Sollberger 1987). Zooplankton densities have historically been higher in the lower basin than the upper basin of Lake Mead (Everett 1972, Paulson et al. 1980). Average zooplankton densities were uniformly low throughout the main basin areas in 1981 and 1982 but were still faily high near the productive inflows (Paulson and Baker 1983a, Wilde 1984).

The limnetic areas of Lake Mead were virtually devoid of shad during the early 1980s, but they were still fairly abundant near the productive inflow areas (Baker and Paulson 1983). Shad are planktivorus (Gerdes and McConnell 1963), and juveniles efficiently crop large zooplankton from the epilimnion during summer months in Lake Mead (Paulson and Baker 1983a, Wilde 1984, Sollberger 1987) and other reservoirs (Applegate and Mullan 1969). Phytoplankton and detritus also comprise important components of their summer diets in Lake Mead (Deacon et al. 1972), and other reservoirs (Haskell 1959, Gerdes and McConnell 1963, Baker and Schmitz 1971). Shad are capable of ingesting relatively small phytoplankton cells by filter feeding in open waters (Haskell 1959). The occurrence of numerous phytoplankton taxa in shad diets from Lake Mead indicates similar feeding behavior (Deacon et al. 1972). Deacon and Tew (1973) also reported that shad were densely congregated near the thermocline during late summer and fall (Figure 3). They believed that shad were drawn to this region to feed on detritus that accumulated during summer. Haskell (1959) contends that phytoplankton and detritus are dietary supplements to principal foods, like zooplankton, that have higher nutritional and caloric values. Shad usually exhibit little growth on detritus due to the poor nutritional quality (Pierce et al. 1981), but if ingested in sufficient quantities, it may allow for survival during periods when zooplankton availability is low.

The decline in productivity, and associated food resources, that occurred in the upper basin of Lake Mead after 1963 and in

Boulder Basin during the late 1970s and early 1980s appears to have had a devasting impact on the limnetic shad population, the main forage base for largemouth bass, striped bass and salmonids. Productivity in most of Lake Mead does not appear to be sufficient to sustain zooplankton production at levels required for good survival of juvenile shad except near the productive inflow areas. Most of Lake Mead is oligotrophic based on every trophic state criteria developed for classifying lakes and reservoirs (Table 1). It is likely to remain that way unless measures are taken to improve fertility. Some additional phosphorus may be routed through Lake Powell during years of high runoff now that it is full. Phosphorus loading appears to have increased in recent years as a result of high runoff in the Colorado River since 1983 (USBR 1987). This may have resulted in a slight increase in chlorophyll-a concentrations during spring, as has been observed in Boulder Basin in recent years (Paulson 1986, Paulson 1987). It may also be the reason for the slight increase in the abundance of shad that has been observed by fishermen in recent years.

Recent proposals have been made to relax phosphorus standards on wastewater discharges during winter months (Paulson and Baker in press). That will help improve fertility in Boulder Basin, but it will have no effect on the upper basin. Exporting wastewaters from Las Vegas to the upper basin would be very costly since a diffuser would probably be necessary to effectively disperse the nutrients. Artificial fertilization seems to provide the only

Table 1. Trophic state of Lake Mead during 1981/1982 and during the 1986 growing season relative to classification criteria found in the literature. Data from 1981/1982 based on area weighted monthly surface composites (0-5m) from all lake stations. 1986 data are averages based on monthly surface composites from May-September from Virgin Basin, three Overton Arm stations, and Gregg Basin. O= oligotrophic, M=mesotrophic, E=eutrophic. TP and chlorophyll-*a* in ppb, and secchi depth (transparency) in meters.

SOURCE	TP			CHLOROPHYLL			SECCHI		
	O	M	E	O	M	E	O	M	E
Criteria (cite)									
(1)	<12	12-25	>25	-	-	-	-	-	-
(8)	<12	12-24	>24	<2.5	2.5-6.5	>6.5	>4.0	2.0-4.0	<2.0
(13)	<15	15-25	>25	<3.0	3.0-7.0	>7.0	>4.0	2.5-4.0	<2.5
(35)	<10	10-20	>20	<2.0	2.0-6.0	>6.0	>4.6	2.7-4.6	<2.7
(38)	<10	10-20	>20	<7.0	7.0-12	>12	3.7	2.0-3.7	<2.0
(39)	<10	10-30	>30	0.3-3.0	2-15	10-500	-	-	-
Lake Mead									
1981-1982	9			1.5			9.5		
1986	9.2			<2			~5		

Citations

(1) = Ahl and Wiederholm 1977. (8) = Carlson 1977. (13) = Forsberg et al. 1978

(35) = Rast and Lee 1978. (38) = U.S. EPA 1974. (39) = Wetzel 1983

feasible method of improving productivity in that part of Lake Mead.

C. Efforts to Restore Fertility and Productivity in Oligotrophic Lakes

Artificial fertilization has been used for many years to improve fish production in nutrient-deficient lakes and ponds (Swingle and Smith 1939). A long-term experimental program has been conducted by C.E. Boyd and co-workers at the Auburn University Agricultural Experiment Station in Alabama. This program has generated numerous reports and publications regarding specific methodological details and clear demonstrations of the efficacy of this approach for improving fish production (e.g. Boyd 1981, Davidson and Boyd 1981, Metzger and Boyd 1980).

Increased external loading of nutrients from artificial fertilization led to higher growth rates, recruitment, survival, and production, and improved condition in white fish in Lake 226 in The Experimental Lakes Area of Canada (Mills 1985).

Artificial fertilization has also been very successfully used on a much larger scale - the commerically important sockeye salmon fisheries in coastal lakes in British Columbia, Canada and in Alaska. The Canadian government has sponsored the Salmonid Enhancement and Lake Enrichment Programs since 1969 to enrich oligotrophic lakes with fertilizer (LeBrasseur et al. 1978, Stockner et al. 1980, Stockner 1981). The program has involved the use of over 100 tons of fertilizer annually, in a variety of lakes ranging to over 5000 surface acres. Results have been very successful and have clearly shown that nutrient enrichment stimulated all levels of the food chain, ultimately increasing the recruitment of sockeye salmon. Increased production at the primary and secondary trophic levels resulted in increased growth of juvenile fish and larger out-migration of smolts (Hyatt and Stockner 1985).

A similar large-scale program was developed in Alaska in the early 1980s for improving sockeye salmon recruitment by fertilizing a number of different size oligotrophic lakes. One in particular, Karluk Lake, is of considerable size (> 5000 acres) and is located in Kodiak National Wildlife Refuge. Initial results indicate that artificial fertilization can enhance the standing stock and recruitment of sockeye salmon (Koenings 1986, Koenings and Burkett 1987). It is of interest that this program uses the same fertilizer formulation (liquid ammonium polyphosphate, 10-34-0) that was used in the 1987 Lake Mead Fertilization Program and is proposed for use in 1988.

Following the completion of a five year study analyzing the factors potentially responsible for the decline of the largemouth bass fishery in Lake Mead, NDOW and AGFD recommended that experimental fertilization be conducted in the upper basin of Lake Mead to begin restoring the forage base (Morgenson and Padilla

1982). Paulson (1984) submitted a proposal for a large-scale tes in the Overton Arm and Gregg Basin, two areas which are distant from downstream water users. The Overton Arm is particularly suitable for test experiments because it is unproductive and morphometrically isolated from the main lake.

The Lake Mead Nutrient Enhancement Technical Committee (LMNETC) was formed in late 1984 to further plan and design this massive experiment. The committee met on numerous occasions in 1985 and 1986, and in 1986 the U.S. Bureau of Reclamation funded UNLV to conduct laboratory and pilot-scale field experiments designed to evaluate the potential for successfully stimulating algal growth on a large-scale in Lake Mead using artificial fertilization. The principal goals were: (1) to determine the most suitable type(s) of fertilizer for large-scale additions to Lake Mead; (2) to evaluate methods of fertilizer application; and (3) to make recommendations regarding the frequency of fertilizer applications. The research plan involved laboratory fertilizer leaching experiments, nutrient enrichment bioassays of natural assemblages of phytoplankton, two test fertilizations in Cathedral Cove (a 32 acre cove near the middle of the Overton Arm) in the summer of 1986, and an evaluation of a variety of methods for actually applying the fertilizer (Axler et al. 1987).

The principal recommendations of the PreFertilization Study were: (1) use commercially available liquid ammonium polyphosphate (10-34-0 "white" formulation); (2) conduct the first large-scale test in the Overton Arm in May; (3) conduct a pilot fertilization of coves in the Overton Arm in the fall for enhancing over-winter survival of forage and gamefish populations; (4) utilize volunteer boats to uniformly disperse liquid fertilizer throughout the test region (Axler et al. 1987). The conclusions and recommendations of this study were directly incorporated into the design of the 1987 Overton Arm Fertilization and the proposed 1988 experiments.

D. Overview of the Lake Mead Fertilization Program - Future Years

The proposed 1988 fertilization is the second year of a three year experimental program that was carefully developed by the LMNETC following an extensive analysis of historical limnological and fisheries data for Lake Mead and a detailed prefertilization pilot study conducted in 1986.

The results from the proposed 1988 experiment will be used to further refine the experimental design of the 1989 project. Neither the proposed 1988 or the anticipated 1989 projects involve substantive changes in the extent of fertilization carried out in 1987.

II. THE OVERTON ARM FERTILIZATION - 1987

The major objectives of the 1987 experiment, the first large-scale (~20,000 acres) fertilization of Lake Mead, were:

- Develop application procedures for uniformly dispersing nutrients in the test region

- Boost phytoplankton biomass and productivity to moderate (mesotrophic) levels for a relatively short period of time (several weeks)

- Intensively monitor algal and zooplankton responses to fertilization; monitor limnetic fish abundance by echosounding

- Intensively monitor water quality in the test region and in control regions in order to assess effects on other beneficial uses of the lake

- Establish community involvement in the project for fertilizing and for assessing fisheries' responses to the nutrient addition

The key elements and results of the 1987 program as they relate to these objectives are discussed in greater detail in the remainder of this section.

A. Permit Process

UNLV submitted a formal proposal for fertilizing the Overton Arm and Gregg Basin of Lake Mead to the LMNETC in January, 1987. It was subsequently determined by the National Park Service (NPS) that an Environmental Assessment (EA) would be required before proceeding with the project. Gregg Basin was subsequently dropped from the proposal for 1987 because of inadequate funding. UNLV prepared a Draft EA which was revised and submitted by the committee to NPS in March, 1987. Application for a National Pollutant Discharge Elimination System (NPDES) permit was made separately by UNLV to the Nevada Division of Environmental Protection (NDEP). After reviewing public comments, NPS authorized the FONSI on May 21, 1987 and granted UNLV permission to proceed with the test contingent upon issuance of the NPDES permit (NPS 1987). Following a 30 day comment period and a public hearing, NDEP issued the NPDES permit (#NV0021393) to UNLV on May 27, 1987.

The NPDES permit specified effluent limitations, monitoring requirements and conditions, and submittal of a final data report prior to October 27, 1987. This report has now been submitted (Axler et al. 1987b) and accepted by NDEP in fulfillment of the monitoring requirements of the permit.

B. Application Methodology and Protocols

Site Description/Fertilizer Formulation/Timing

The fertilization region and the morphometric characteristics of the region which were used to calculate the fertilizer tonnage required are described in Figure 7 and Table 2. Liquid ammonium polyphosphate (10-34-0, white formulation) was chosen based on the recommendations of the Pre-Fertilization Study (Axler et al. 1987). The liquid mixes thoroughly with lake water which eliminates some of the difficulties associated with incomplete dissolution of granular formulations and insoluble residues.

The proposed spike was expected to stimulate algal growth to levels of 5-10 ug/l of chlorophyll-a which would represent a moderately productive body of water and produce no degradation of other beneficial uses of the water.

It was particularly important to perform this initial experiment relatively early in the growing season but after stable stratification had occurred. The thermocline would act to restrict the soluble fertilizer to the upper mixed layer where most of the algal production occurs. Further, during spring and early summer there is still sufficient inorganic-nitrogen (mostly as nitrate) present to provide a balanced N:P ratio for algal growth (7-15:1) (Healey 1973, Goldman and Horne 1983). Late summer fertilization would require an additional supplement of

Figure 7 Lake Mead -- Fertilization study sampling sites

(cross-hatch = fertilization)

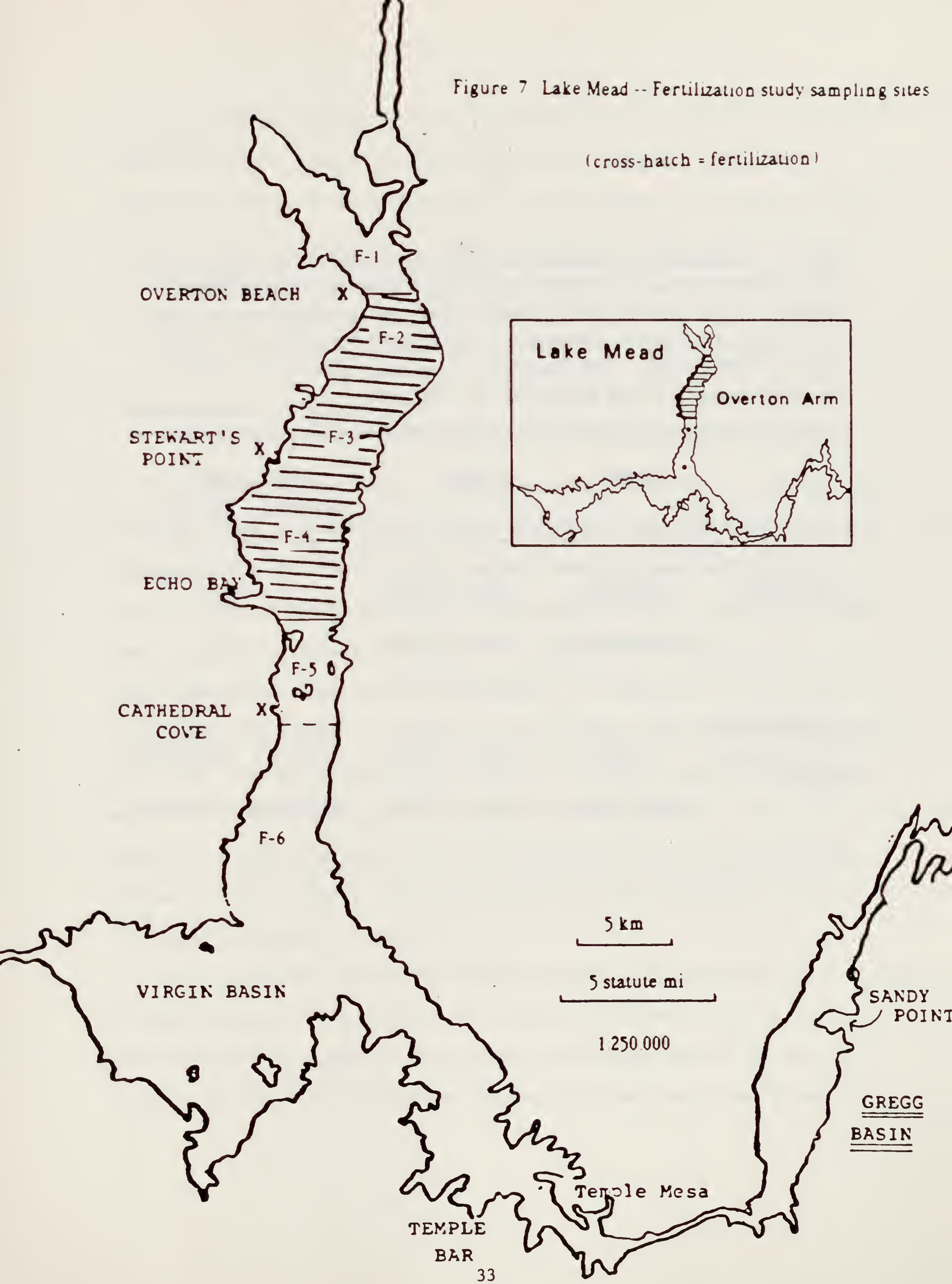


Table 2 Morphometric characteristics of Lake Mead (at full capacity) and the epilimnion of the Overton Arm assuming a water surface at 366m elevation (1200 feet MSL) and a thermocline depth of 13m. The fertilizer quantities are for liquid ammonium polyphosphate (formulation 10-34-0) which is 10% nitrogen, 15% phosphorus, and has a density of ~1.4 g/cc. The totals assume a final enrichment of + 20 µgP/l.

	AREA	VOLUME	FERTILIZER volume	FERTILIZER weight
LAKE MEAD:	66096 ha	36.9×10^9 m3	--	--
	163,320 acres	29.9×10^6 a-f		
OVERTON ARM: (Fertilization Region)	7669 ha	0.854×10^9 m^3	75.7 m^3	106 tonnes
	18,950 acres	0.692×10^6 a-f	20,000 gal	117 tons

nitrogen since inorganic-N is depleted to near detection limits (Paulson et al. 1980, Paulson and Baker 1983a,b; USBR 1987). The supplement would probably have to be at least five times greater in weight than the P-fertilizer, as was necessary during the two pilot studies in Cathedral Cove in August and September, 1986 (Axler et al. 1987).

Method of Application

Volunteers from local, regional, and national fishing and boating clubs donated their time and boats to apply fertilizer. Approximately 300 boats were needed, each spreading about 70 gallons of liquid fertilizer, to complete the job. There has been great interest in this project from local and regional sportsmen (see Appendix 1), and we anticipated no difficulty in attracting sufficient volunteers. This was the least expensive method of application and also generated support from sportsmen for involvement with future management programs at Lake Mead. This could be especially significant to NPS in achieving their new management agenda which strongly encourages public participation in critical resource management issues.

Solicitations for help began in February, 1987 and by the day of fertilization, 361 boats had been registered along with about 1000 people. A computer data base was established for storing mailing lists and information regarding boat and crew size, and ground support. Three public meetings were held in April and May to explain the project and assign work tasks. Attendance was approximately 300 at each. Presentations were made by UNLV scientists, the NPS, NDOW, and the Lake Mead Fishing Enhancement Society - an organization comprised of officers from local fishing clubs, fishing guides, and concerned sportsmen.

Fertilizer was delivered in five, 4000 gallon tanker trucks beginning two weeks before the application. The 20,000 gallons were dispensed into 4400, five gallon plastic jugs ("cubitainers"). Boat captains were assigned jugs according to the size of their boats and asked to pick them up prior to May 30. Moored boats were loaded from barges at Echo Bay. In order to ensure uniform distribution of nutrients to the fertilization region, we arranged boats in three rows across the lake from west to east (see Appendix 2). Each row was controlled by primary and secondary group leaders in radio contact with UNLV and NPS personnel in guide boats. The differing loads of each row were compensated by adjusting the lake area coverage for each row to obtain the desired final concentration of nutrients (~ 20 ugP/l) in the fertilization region.

C. Fertilization Day - May 30, 1987

The application procedure worked extremely well. An Incident Command System set up by the NPS helped ensure a minimum of problems associated with parking, launching, and boating safety. Additional patrol boats were manned by NDOW and the U.S. Coast Guard Auxiliary. The fertilizer was dispersed according to plan. everyone had a good time and seemed enthusiastic about participating in follow-up programs (Appendix 1).

D. Monitoring Program

Intensive limnological monitoring was carried out during the study. The basic sampling program was conducted at six stations in the Overton Arm (see Figure 7). Three additional synoptic surveys were also performed before and after the fertilization. Epilimnetic composites (0-5 m) were routinely analyzed for ammonium, nitrate + nitrite, ortho-P, total-P, total-N, chlorophyll-a, phytoplankton density and species enumeration, and ^{14}C-primary productivity (PPr). Additional water column vertical profiles of these parameters were also determined in the fertilization and control areas for a number of dates. All of these analytical methods were performed according to the standard procedures used by the UNLV Limnological Research Center (Kellar et al. 1981).

Secchi depth, hydrolab profiles (pH, DO, EC, Temp.), and light intensity profiles (with a quantum photometer) were routinely determined at all sites.

Fertilization effects on the zooplankton community were addressed in three ways:

(1) Densities, biomass and community composition

(2) Species-specific growth rates and secondary productivity using cohort analyses. This analysis is being performed by Dr. C.L. Folt at Dartmouth University who is conducting a detailed cohort analysis of the major species (Edmondson and Winberg 1971).

(3) Nutritional status of cladocerans using the lipid-ovary index and egg ratios (Tessier and Goulden 1982, Bjorkman and Shapiro 1986).

Relative abundance and distribution of shad were estimated by routine echosounding transects as has been done historically. In addition, shad were collected by trawling to assess the size, growth and food habits of juveniles.

E. Preliminary Results

Overall, the experiment was extremely successful and the lake responded to nutrient enrichment much as had been predicted in the EA for the project (Table 3, Axler et al. In Press). Phytoplankton biomass and productivity increased by factors of 3-5 to reach "moderate" levels which returned to baseline conditions within 2-3 weeks. Cladoceran zooplankton responded with an in-

Table 3. Changes in certain limnological parameters in the fertilized region (mean values from 0-5m composites from stations F-2/3/4) following the 1987 Overton Arm Fertilization. ✓ = *as predicted in the Lake Mead Fertilization Project Environmental Assessment* (LMNETC, 1987).

PARAMETER	(5/14-5/27) PRE	(5/31-6/16) FERT	(6/24-7/8) POST	NOTES
Total-P (ppb)	7-11	46 max, 23 mean (day 1)	7-13 (day 8)	✓, slightly higher TP due to stratification pattern
NH_4-N (ppb)	< 10	24 max (day 1)	< 10 (day 2)	✓
NO_3-N (ppb)	150-180	depletion to <20	<20	✓, rate of depletion increased from -3-14 gN/L/day
Total -N	.... no significant effects			✓
pH	8.4-8.6	8.4-8.8	8.4-8.5	✓
EC	~815-850 :	no effect due to fertilization		✓
DO (ppm)	saturated	supersaturated (120-150% @ midday)	saturated	✓
Chlor-a (ppb)	<2	3-11 (day 3 to13)	≤ 2	✓ (>5ppb for 4 days)
Clarity (extinction of PAR, 0-10m, as k, m^{-1})	0.26-0.36 (~30% reduction during the first week, <20% after 2 weeks)	0.37-0.48	0.41-0.27	✓
Zooplankton	dramatic increase in nutritional reserves and in egg production			✓
Threadfin Shad	apparent increase in shad densities as noted on echograms and by trawling			✓
Gamefish	apparent increases in striped bass activity (surface "boils") and condition factors			✓

crease in density, reproductive rate and improved nutritional status. Perhaps the most dramatic result, however, was that it appeared that there was a dramatic increase in the distribution and abundance of threadfin shad, beginning a few days after the fertilization. It appears that increased algal and zooplankton biomass may have increased the survival of larval shad during the first few critical days after hatching when they are most likely to be food-limited (Kilambi and Barger 1975, c.f. May 1974).

The increase in shad abundance and distribution appears to have dramatically stimulated surface feeding activity by striped bass in the fertilization region. As a result, fishing success has improved and the condition of creeled fish has increased.

No adverse impacts on water quality were observed due to the fertilization. Water clarity in the fertilized region did decline by 30% during the first week, but this effect was reduced to less than 20% after two weeks. There was no increase in the salinity of the water and the nutrient increases associated with the fertilization had returned to baseline conditions in about a week.

More specific details and our major results are presented below.

General Water Quality

No adverse impacts on the beneficial uses of the lake resulted from the fertilization, as predicted in the Environmental

Assessment (LMNETC 1987, Table 3).

In particular, we also note that the fertilizer addition did not increase the salinity of the lake, a concern which arose during the comment period for the EA. This topic was thoroughly addressed in the Pre-Fertilization Study (Axler et al. 1987) and further demonstrated in the current study. It is apparent from Figure 8, Table 4, and Table 5 that although differences between stations existed before and after the application, fertilization did not increase the electrical conductivity, TDS, or major ion composition at individual stations. The north-south gradient in EC in the Arm has been noted historically and is maintained by influences from the Virgin and Muddy Rivers.

Water transparency was determined using vertical profiles of photosynthetically active radiation and as Secchi depth (Figure 9). It can be seen that temporary reductions in water clarity occurred which lasted about three weeks. It is also important to note that the major decreases in Secchi depth were due to naturally occurring sources of turbidity, largely silt, which were observed prior to fertilization and at all control stations. Fertilization effects were essentially insignificant by about Day 25.

No objectionable odors in the fertilization region were ever noted by any member of the UNLV sampling crew nor were any such reports ever brought to the attention of us, (D. McLean, pers. comm. July 8, 1987), or the management of Echo Bay Resort (J. Burns, pers. comm., numerous dates in June and July 1987).

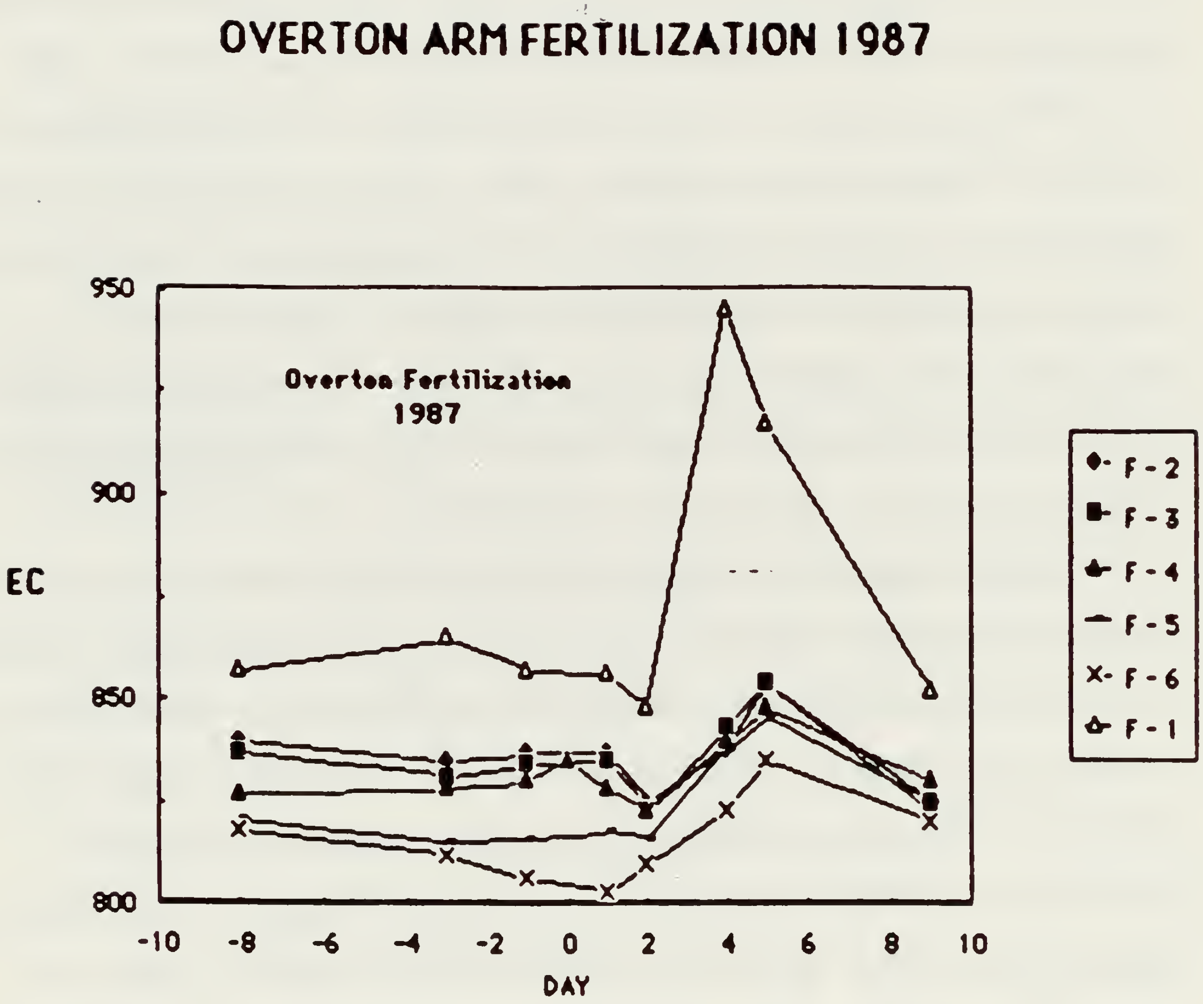


Figure 8. Electrical conductivity for Overton Arm Fertilization stations. EC in umhos/cm averaged over the upper 5m. Fertilized region included F2, F3, and F4. Day 0= May 30, 1987.

Table 4. Results of U.S. Bureau of Reclamation (lower Colorado Region, Soil and Water Laboratory, Boulder City, NV) analyses for major anions and cations (mg/l), electrical conductivity (EC, in µmhos/cm), pH, and TDS (mg/l) from the Overton Arm on May 31, 1987 (one day after fertilization). Samples are 0-5m composites. Also tabulated are EC field measurements (mean values from 0-5m) taken at the same time as the water collection and on May 29, the day before the fertilization. FZ = mean of F2 + F3 + F4.

PARAMETER	N. Control	Fertilized Zone			$\overline{\text{FZ}}$	S. Controls	
	F1	F2	F3	F4	F2/3/4	F5	F6
Ca	75	77	75	73	75	72	71
Mg	26	26	26	25	26	25	24
Na	68	67	67	66	67	64	63
K	5	5	5	5	5	5	5
SO4	228	216	216	218	217	209	199
HCO3	144	124	112	137	124	134	146
CO3	12	12	14	19	15	17	10
Cl	67	57	60	59	59	55	51
SiO2	9	8	8	9	8	9	8
pH	8.4	8.5	8.5	8.5	8.5	8.5	8.4
TDS (evap)	588	579	577	575	577	555	550
EC	865	850	851	843	848	834	813
EC* (UNLV)	856	837	835	828	833	818	803
EC** (UNLV)	857	837	834	830	834	816	806

* Field measurement on May 31, 1987 at time of USBR water collections

** Field measurement on May 29, 1987 prior to fertilization

Table 5. Results of U.S. Bureau of Reclamation (Lower Colorado region, Soil and water Laboratory, Boulder City, NV) analyses for major cations and anions (mg/l), electrical conductivity (EC, in µmhos/cm) and TDS (mg/l) from the Overton Arm. Station F4 in the fertilized zone and F6 at the southern control area were monitored monthly as stations LM19 and LM18, respectively, for the USBR in 1986 and 1987. Data from 5-31 are part of a set that also includes F1, F2, F3, and F5 which were all sampled one day after fertilization. All samples were surface water except on 5-31, which were 0-5m composites.

	CA		MG		NA		K	
DATE 1987	F4	F6	F4	F6	F4	F6	F4	F6
3-18	68	67	23	23	61	61	3.1	3.1
4-15	70	70	24	24	64	62	3.1	3.5
5-14	71	69	24	24	64	63	3.1	3.1
5-31	73	71	25	24	66	63	5.0	5.0
6-17	66	68	25	25	65	64	5.1	5.1

	SO4		HCO3		CO3		CL	
3-18	196	194	165	159	0	0	51	47
4-15	205	192	161	160	0	0	55	53
5-14	211	198	151	160	11	6	54	51
5-31	218	199	137	146	19	10	59	51
6-17	212	208	117	119	13	12	53	52

	EC		TDS	
3-18	796	798	522	521
4-15	823	810	545	521
5-14	825	805	526	512
5-31	843	813	575	550
6-17	818	820	545	527

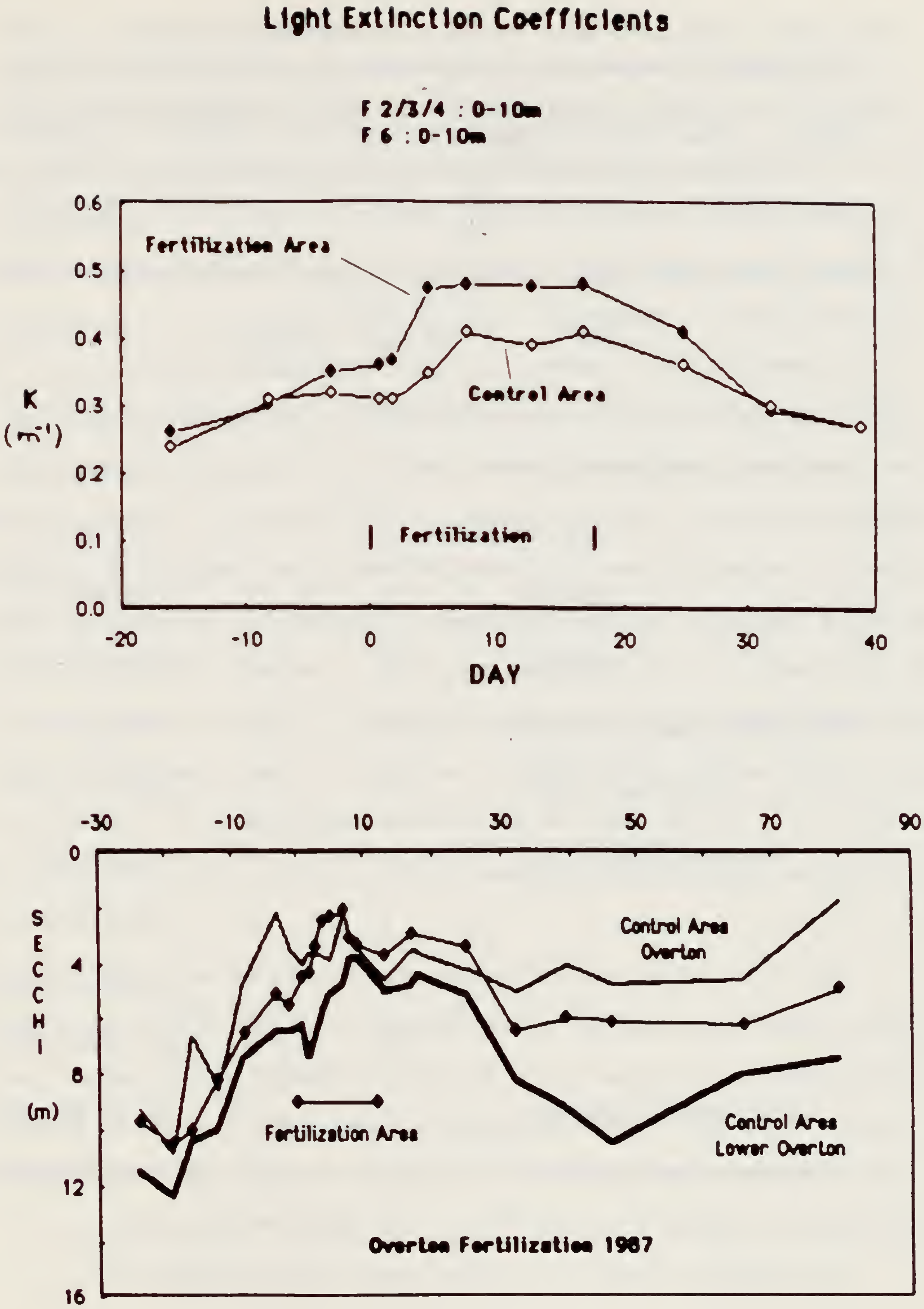


Figure 9. Variation in light extinction coefficients and Secchi disc depth in fertilized and control areas of the Overton Arm of Lake Mead (Days numbered relative to Fertilization Day, 5/30/87)

We also collected water samples on Day 5 and Day 18 and analyzed them for threshold odor numbers. Samples were collected as surface dips in glass-stoppered glass bottles, stored on ice, and delivered to the laboratory within 24 hours of sampling. Analyses were performed immediately upon delivery and the results are tabulated in Table 6.

Threshold Odor Number (T.O.N.) represents the dilution ratio (with high purity odor-free deionized or distilled water) at which odor is just detectable (APHA 1980). According to state and federal drinking water standards, a value of 3 or lower is acceptable for domestic use. It can be seen that fertilization did not produce markedly odiferous water. The fertilized region where F-2, F-3, and F-4 are located had T.O.N. values of 3 or 4 during both the period of peak algal biomass (~ June 4) and after the algal response had dramatically declined to near baseline levels (June 17). T.O.N. values at control stations F-1, F-5 and F-6 were also either 3 or 4 except for a T.O.N. of 2 for F-6 on June 4.

The low T.O.N. values measured for deionized water on both dates offer some degree of confidence in these data, although anomalously low values were found for Rogers Spring water (a hot mineral spring). Taken together, these data and field observations clearly demonstrate that the fertilization of the Overton Arm did not significantly affect the odor of the water.

No adverse impacts on water quality as related to

Table 6. Threshold Odor Numbers (T.O.N.'s) for Lake Mead water associated with the Overton Arm Fertilization. Samples analyzed in the Southern Nevada Water System laboratory within 24 hours of collection (iced during storage). 1 = No odor, 3 = acceptable for domestic water supply, 4 = unacceptable (without treatment) for domestic water supply. Note that chlorophyll levels in the fertilized areas had returned to baseline values by 6/17/87.

Station ID	6/4/87	6/17/87	Notes
F-1 (Overton)	4	3	North control station (unfertilized)
F-2 (Salt Bay)	4	4	Fertilized
F-3 (Stewarts Pt)	3	4	Fertilized
F-4 (Rogers Bay)	4	3	Fertilized
F-5 (Bighorn I.)	4	4	Control (increased algae on 6/4/87)
F-6 (L. Overton)	2	4	Control (always valid)
Virgin Basin	1	3	Clarity higher on 6/17/87
Boulder Basin	-	2	-
BC-5 (mid LVB)	-	4	-
BC-2 (inner LVB)	-	4	-
Rogers Spring	1,1	-	Pond fed by hot mineral spring
Deionized Water	1,1,2	1.4, 1.4	High-purity odor-free water (Milli-Q)

temperature, dissolved oxygen (DO), or pH were observed. Elevated DO values (supersaturated to ~ 120-150% at midday) were measured in the epilimnion of the fertilized region during the first two weeks after fertilization. No adverse impacts on aquatic organisms would result from this increase. DO levels would be expected to decrease to near, or somewhat below saturation values at night when there is no photosynthetic production of oxygen. The moderate chlorophyll levels measured (peak values of 8-11 ug/l) were not high enough to cause significant DO depletion during the night.

Differences in pH between stations and dates were generally quite small. No temperature differences were directly attributable to fertilization.

Nutrients

Trends in surface water and depth profiles of nutrient concentrations (ammonia-N, nitrate + nitrite-N, total-N, ortho-P, total-P) are presented in Figures 10 and 11 and the complete data set can be found in Axler and Paulson 1987. An overall summary of these data for the period of the experiment is presented in Table 3, with reference to predictions made in the EA for the project.

From all of these data, we have concluded the following:

1. A relatively small increase (~20 ugN/l) in ammonia-N due to

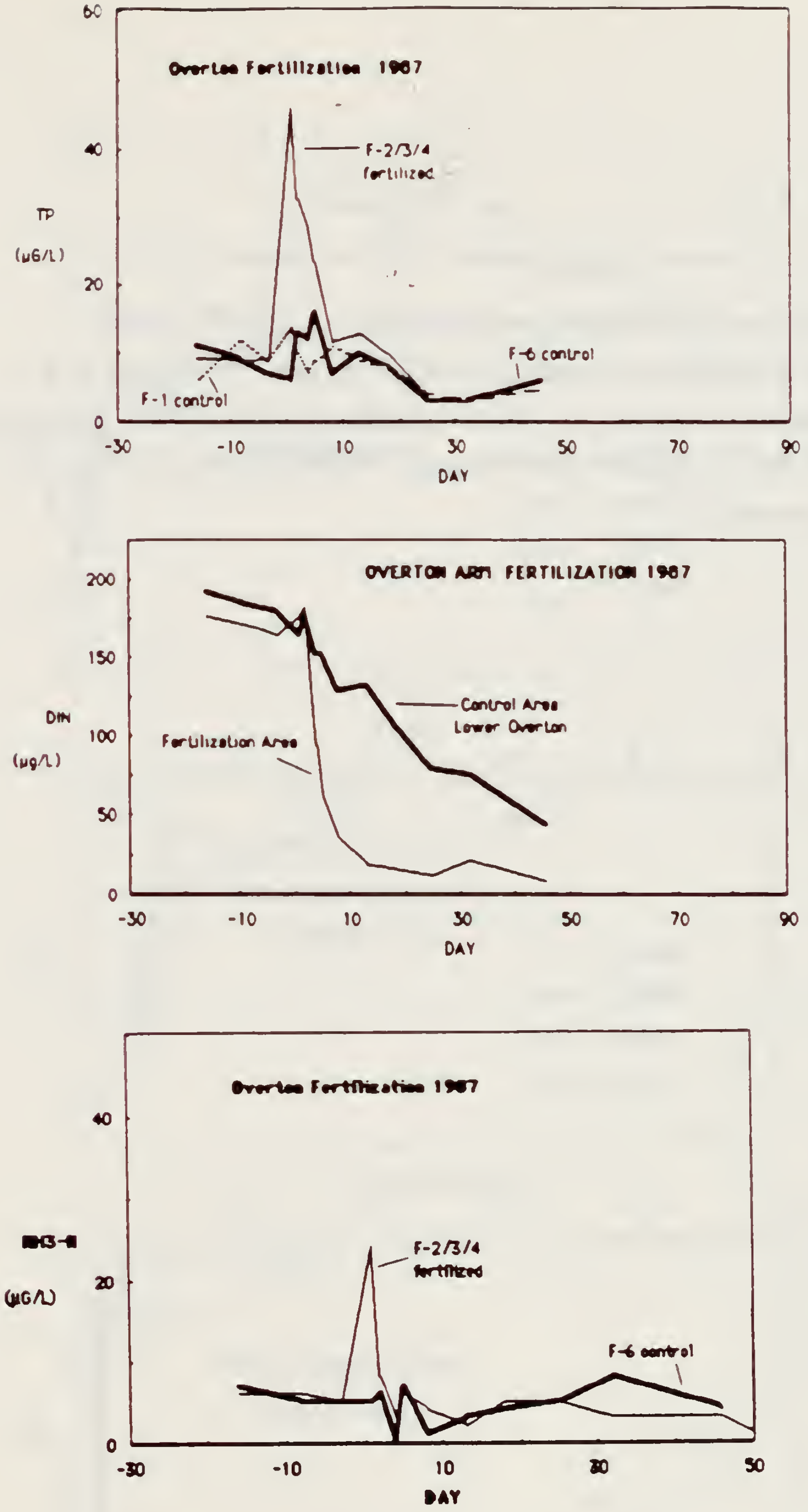


Figure 10. Concentrations of total-P, dissolved inorganic nitrogen and ammonia-N in fertilized (F-2/3/4 mean) and in southern control (F-6) regions of Overton Arm. Data from 0-5m integrated water samples. Day 0 = 30 May, 1987.

Figure 11 Vertical profiles of chlorophyll fluorescence, total-P, ortho-P nitrate and ammonia concentrations during the 1987 Overton Arm Fertilization at station F-4 in the fertilized region. Fertilizer was applied May 30, 1987. A fluorescence value of 300 corresponded to about 11 ug/l of chlorophyll-a.

Figure 11

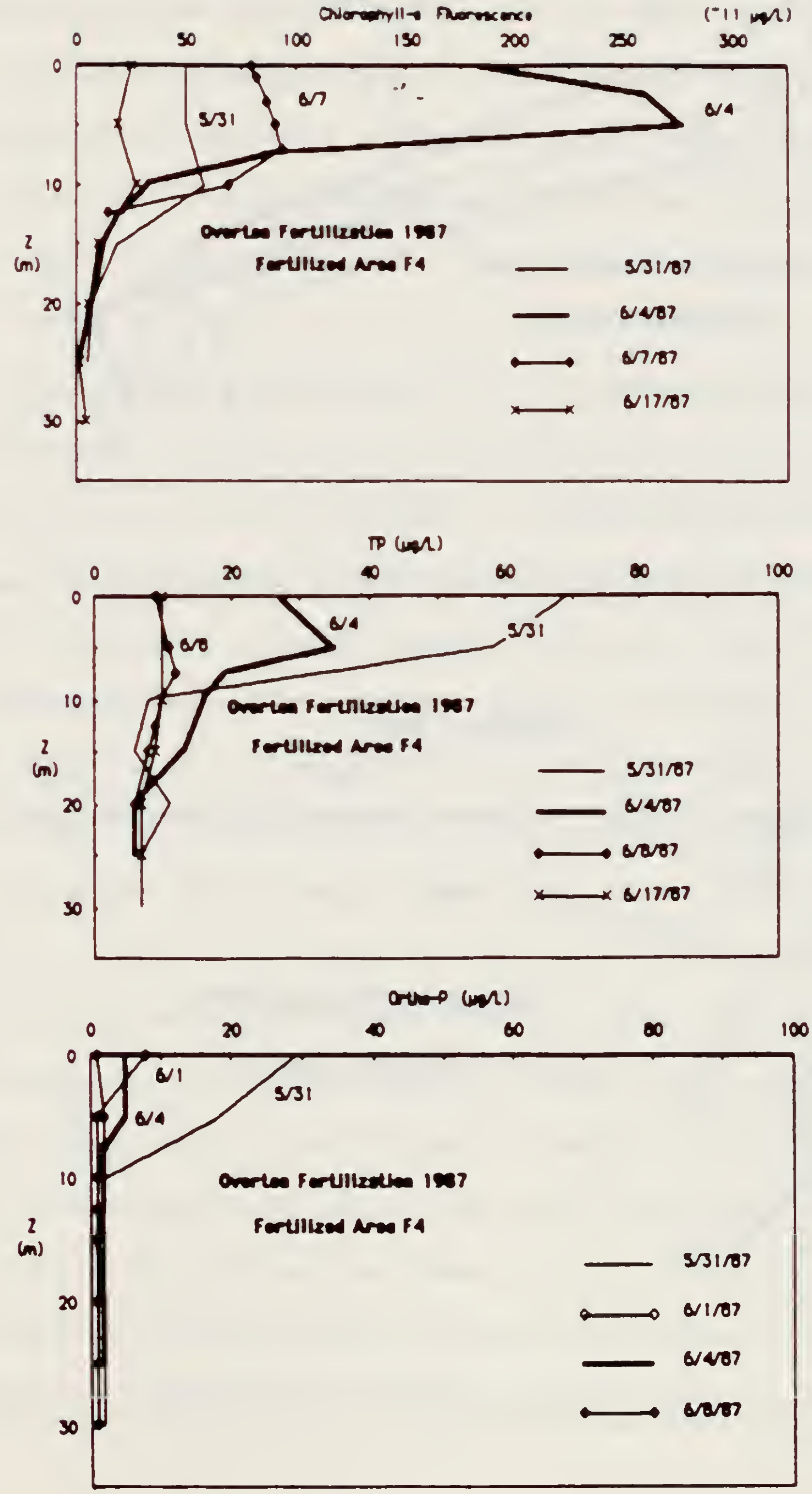
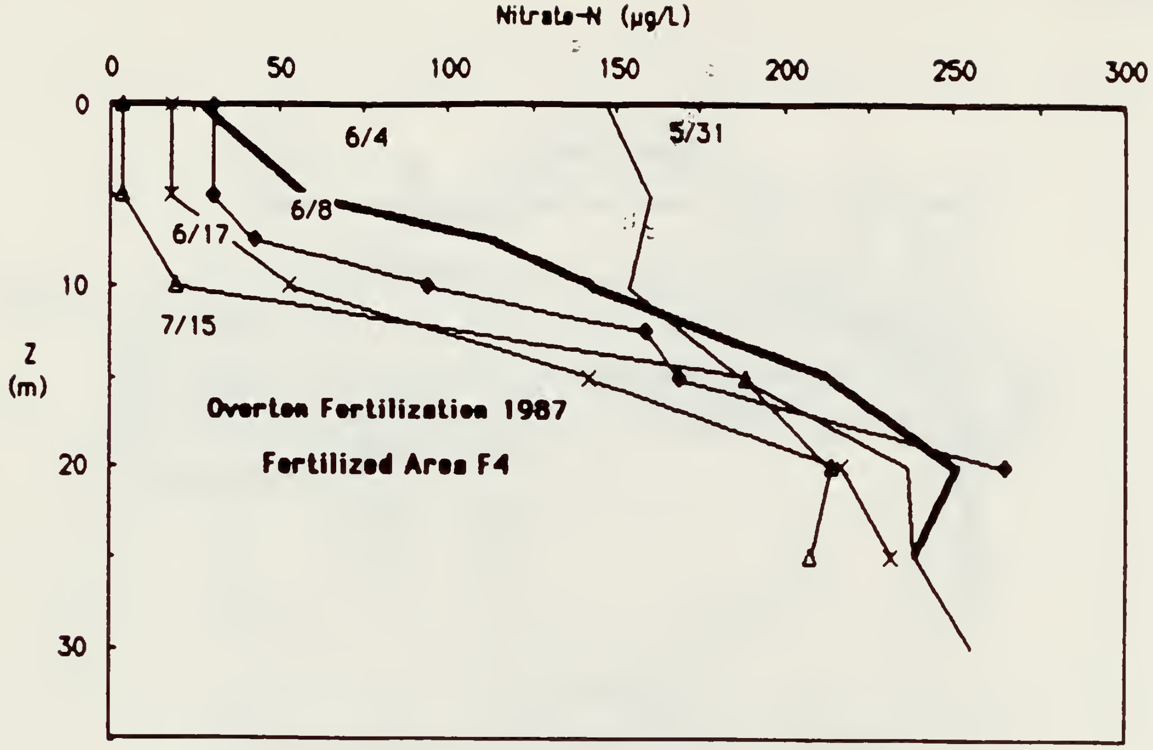
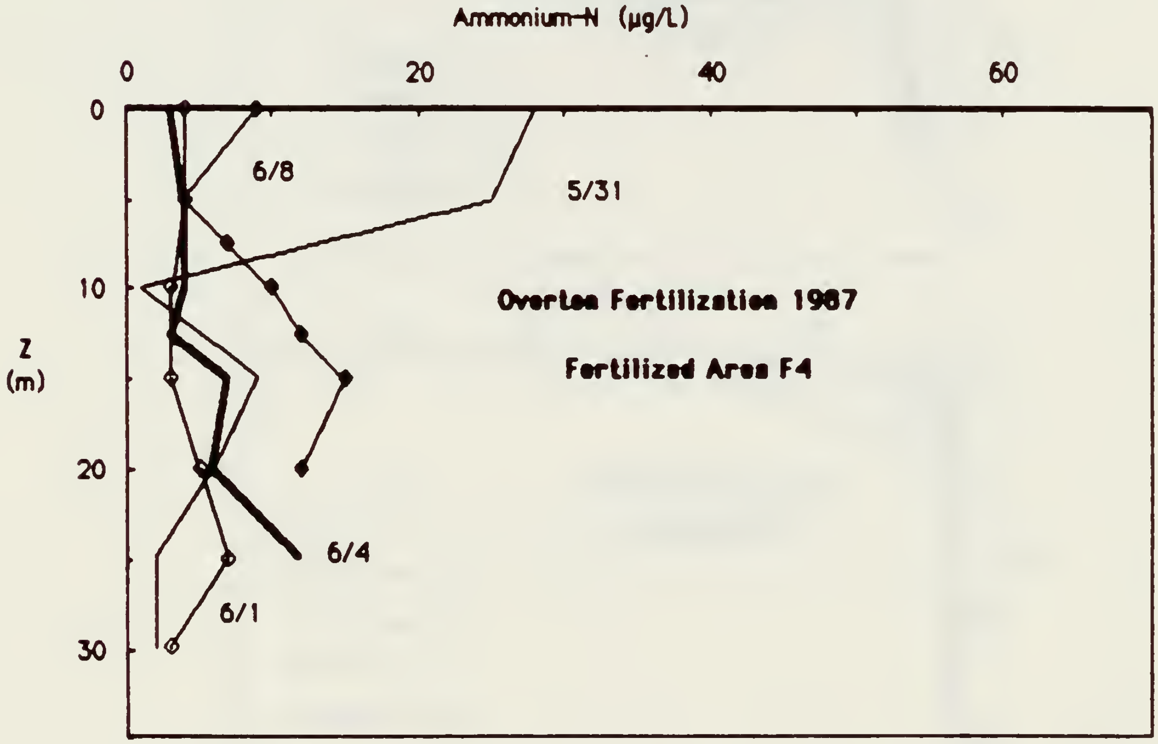

Chlorophyll-a Fluorescence (*11 µg/L)
0
50
100
150
200
250
300
0
10
20
30
Z (m)
6/7
5/31
6/4
Overlea Fertilization 1987
Fertilized Area F4
5/31/87
6/4/87
6/7/87
6/17/87
TP (µg/L)
0
20
40
60
80
100
0
10
20
30
Z (m)
6/4
6/8
5/31
Overlea Fertilization 1987
Fertilized Area F4
5/31/87
6/4/87
6/8/87
6/17/87
Ortho-P (µg/L)
0
20
40
60
80
100
0
10
20
30
Z (m)
6/1
5/31
6/4
Overlea Fertilization 1987
Fertilized Area F4
5/31/87
6/1/87
6/4/87
6/8/87

Figure 11


Nitrate-N (μg/L)
0
50
100
150
200
250
300
0
10
20
30
Z (m)
6/4
5/31
6/8
6/17
7/15
Overton Fertilization 1987
Fertilized Area F4


Ammonium-N (μg/L)
0
20
40
60
0
10
20
30
Z (m)
6/8
5/31
Overton Fertilization 1987
Fertilized Area F4
6/4
6/1

fertilization persisted for less than two days, after which levels in the fertilized region were indistinguishable from either baseline or control station data. Un-ionized ammonia levels, calculated from pH, temperature and ammonia-N concentrations were always $\leq$ 4 ugN/l and usually $<$ 1 ugN/l - far below the proposed state and federal water quality standards designed to protect aquatic life in Lake Mead.

2. No nitrate was discharged during the experiment. However, increased phytoplankton growth in the fertilized region increased the rate of algal nitrate uptake. Nitrate depletion to near-detection limits typically occurs by late summer in Lake Mead and so the fertilization simply accelerated this natural decline. Nitrate concentrations at control station F-6 were, in fact, approaching the limit of detection by early September, approximately 90 days after the fertilization. No adverse impacts on water quality could be attributed to this accelerated nitrate depletion.

3. Total-N concentrations did not indicate any adverse water quality impacts. The fertilizer nitrogen yield was too low to be accurately measured in the TN pool. Levels of TN would be expected to gradually decline during the growing season as inputs of nitrate from river inflow decrease and as available nitrate and ammonia (DIN) are assimilated by phytoplankton, some of which is then "lost" to zooplankton grazing, sedimentation, and dispersion.

4. Orthophosphorus increases due to fertilization were short-term, persisting for < 2 days. Maximum ortho-P levels in 0-5 m composite water samples were 24 and 20 ug P/l (ppb P) at stations F-3 and F-4, respectively on the first day after fertilization. Concentrations were near detection a few days later.

5. Total phosphorus levels in the fertilization region returned to baseline levels within 8 days of fertilization. Levels ≥ 25 ugP/l in 0-5 m composite samples from the fertilized area only persisted for 4-5 days.

It is apparent that the higher levels of dissolved fertilizer nutrients in the upper water column rapidly decreased to baseline levels within a few days. This was due to a combination of vertical mixing within the epilimnion and phytoplankton assimilation of inorganic N and P. Nutrient deficient phytoplankton are well known to be able to efficiently and rapidly take up low levels of dissolved nutrients (Healey 1973, Axler et al. 1981, 1982; Tarapchak and Nalewajko 1986). It was also noted (and calculations presented) in the EA that even the southern-most portion of the fertilization region was still located about 60 km distant from the hypolimnetic drinking water inlet for the Las Vegas Metropolitan Area and from Hoover Dam which discharges hypolimnetic water to downstream users. Consequently, even if fertilizer were not biologically assimilated in the Overton Arm, consideration of dilution in the main basins of the lake in addition to isolation by thermal stratification clearly indicate that downlake water quality degradation was not possible at the application rates used.

Algal Biomass

Chlorophyll-a concentrations for all six stations are plotted over time in Figure 12. It can be seen that fertilization caused a sharp increase in phytoplankton, as estimated by chlorophyll-a, which peaked within several days of the spike, and then declined rapidly to baseline levels in about two weeks.

We also conducted three intensive synoptic surveys, one prior to fertilization, one on Day+4 (near the peak response) and one on Day+9 (during the decline). Samples were collected at east and west laterals in addition to the center channel stations, and along several other east-west transects. Chlorophyll-a concentrations were estimated from in vivo fluorescence values which were converted to chlorophyll-a values using a regression equation developed from the entire data set during the period 22 May - 12 June. The data are plotted in Figure 13 to show the north-south gradients in chlorophyll-a. The standard deviations about the center channel stations are indicative of east-west variability. These data are also presented as isopleths for the three dates in

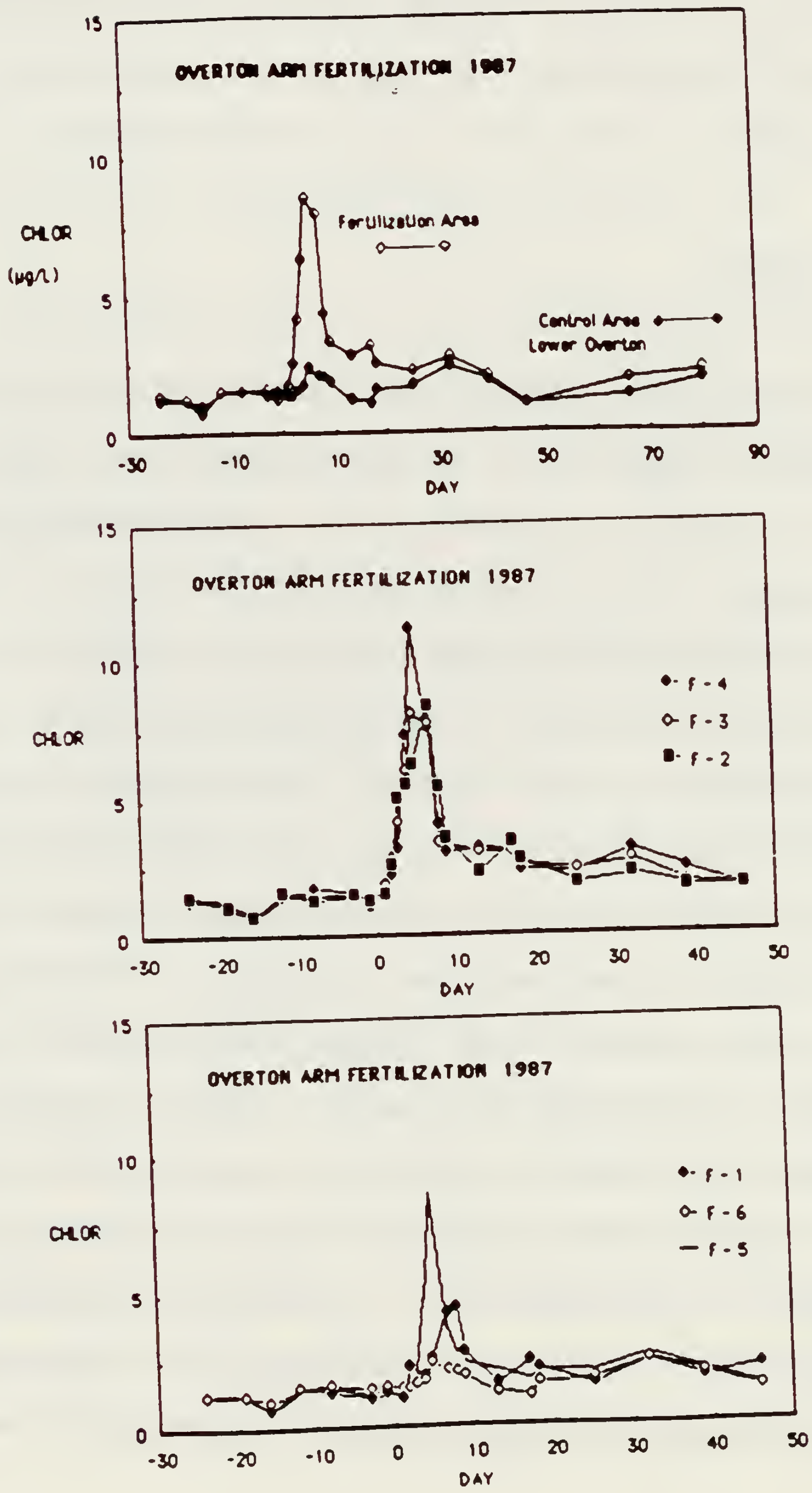


Figure 12 Chlorophyll-a concentrations for 0-5m composites Fertilization area = mean of F-2, F-3 and F-4 Control areas are F-1, F-5 and F-6 Day 0 = May 30, 1987

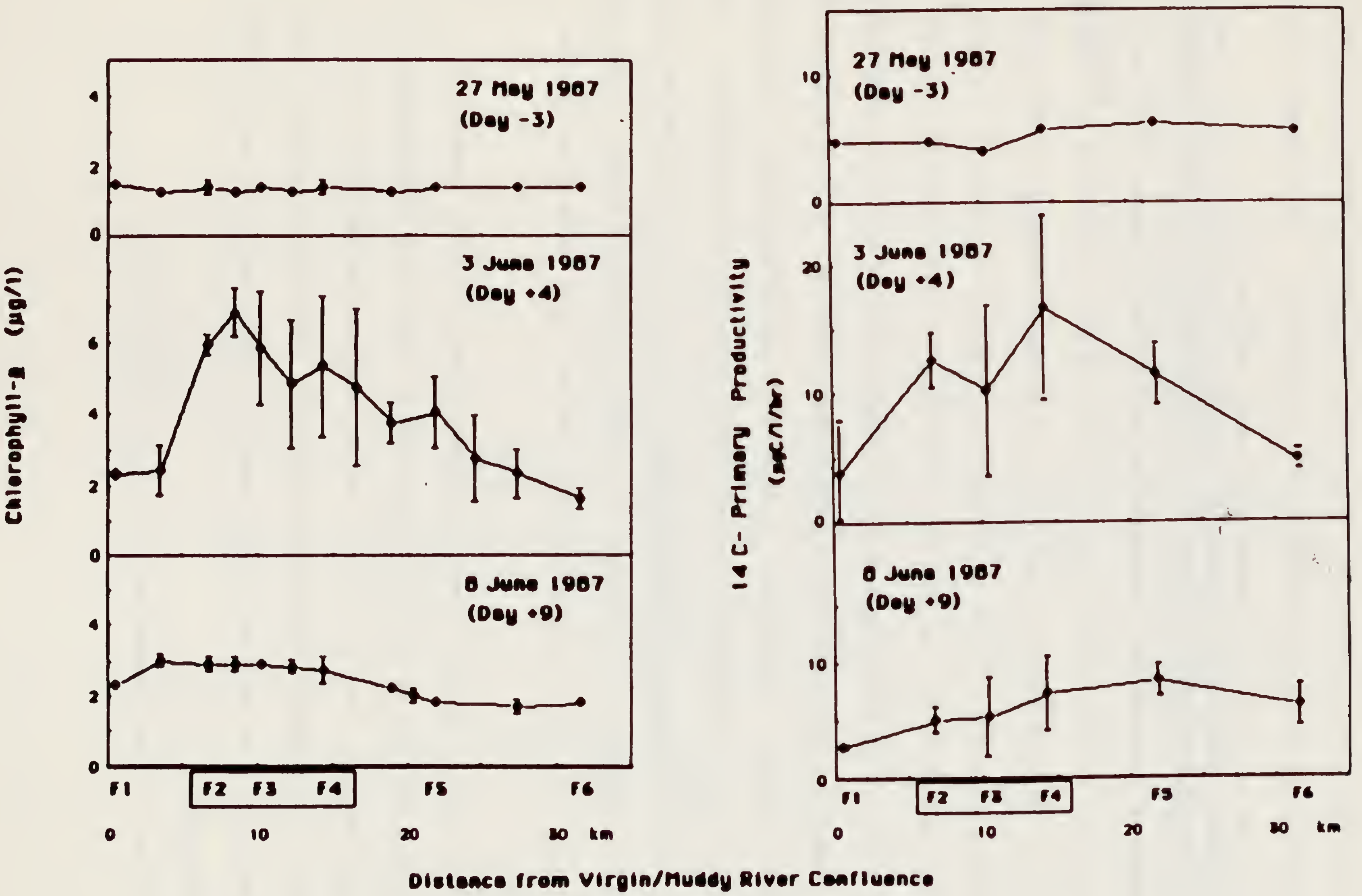


Figure 13 Chlorophyll-a concentrations and rates of ^{14}C-primary productivity measured for 0-5m composites of water collected in the Overton Arm during three intensive synoptic studies. Day 0 (fertilization) = May 30, 1987 Stations F-2, F-3 and F-4 were within the fertilized zone.

Figure 14.

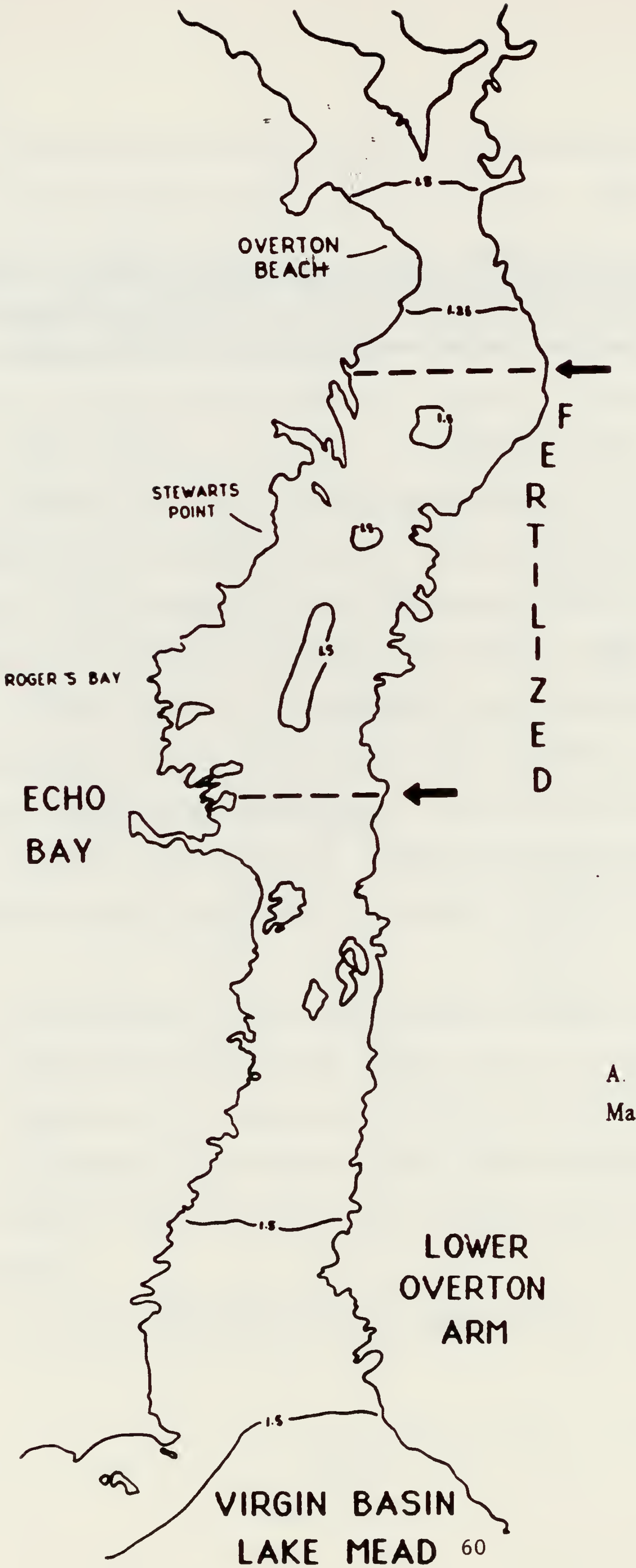
Vertical profiles of chlorophyll-a-fluorescence from the fertilization region are presented in Figure 11a. The rapid increase and decline of algal biomass are again apparent.

Biomass estimates based on cell-enumerations and species identifications showed the same general patterns as for chlorophyll. Fertilized and control region estimates are compared in Figure 15 for Day+4, just prior to peak response. Although the complete analysis of the phytoplankton data is not yet available, it is clear that the major response was by nanoplankton cells < 50 um in size. Cryptomonads and chrysophytes, which are considered to be readily available to zooplankton (Wetzel 1983), showed the greatest biomass increase. Bluegreens (cyanobacteria) were apparently not stimulated significantly by the fertilization. In particular, Microcystis aeruginosa, a scum-forming species which has been a source of concern at times in the eutrophic Inner Las Vegas Bay, was not identified in the May and June Overton Arm samples.

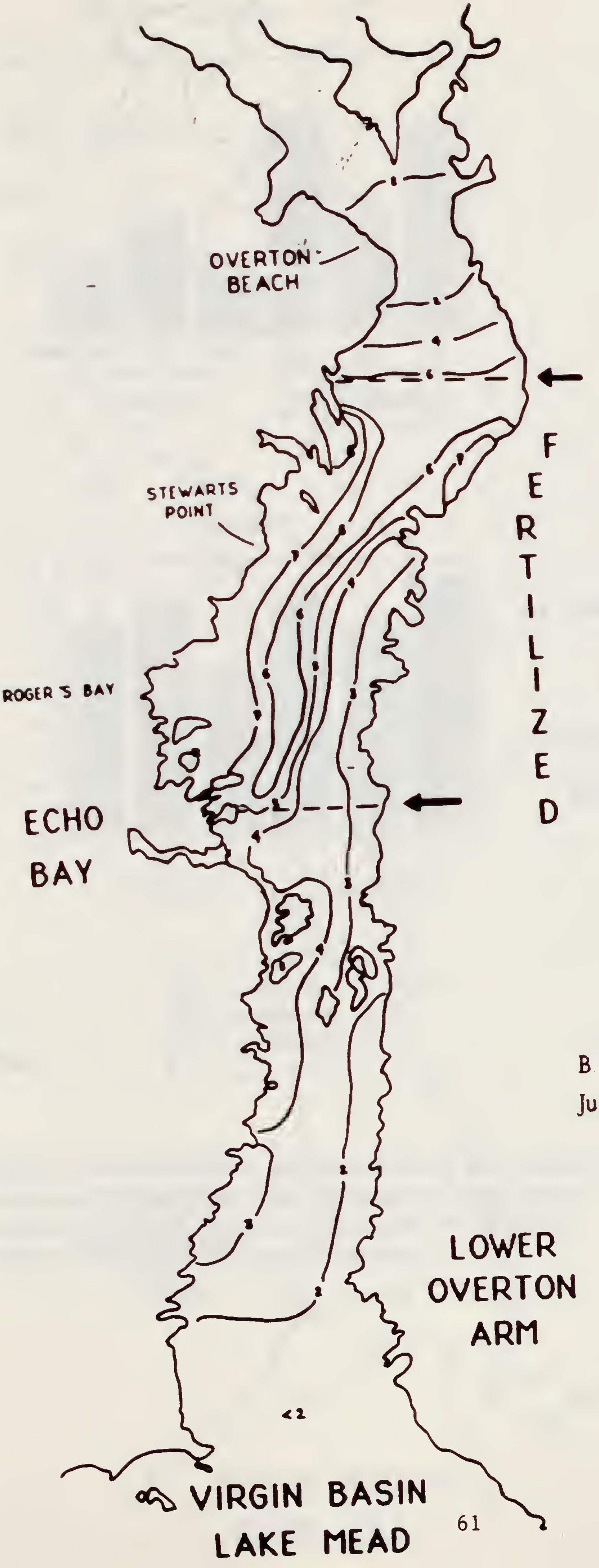
Periphyton growth was surveyed approximately weekly by visually inspecting boats, boat docks, and tire breakwaters in the Echo Bay Marina and by interviewing marina personnel. No increases in attached algae were found. This was expected since virtually all of the nutrient addition was rapidly assimilated by phytoplankton.

From all of these data it is evident that:

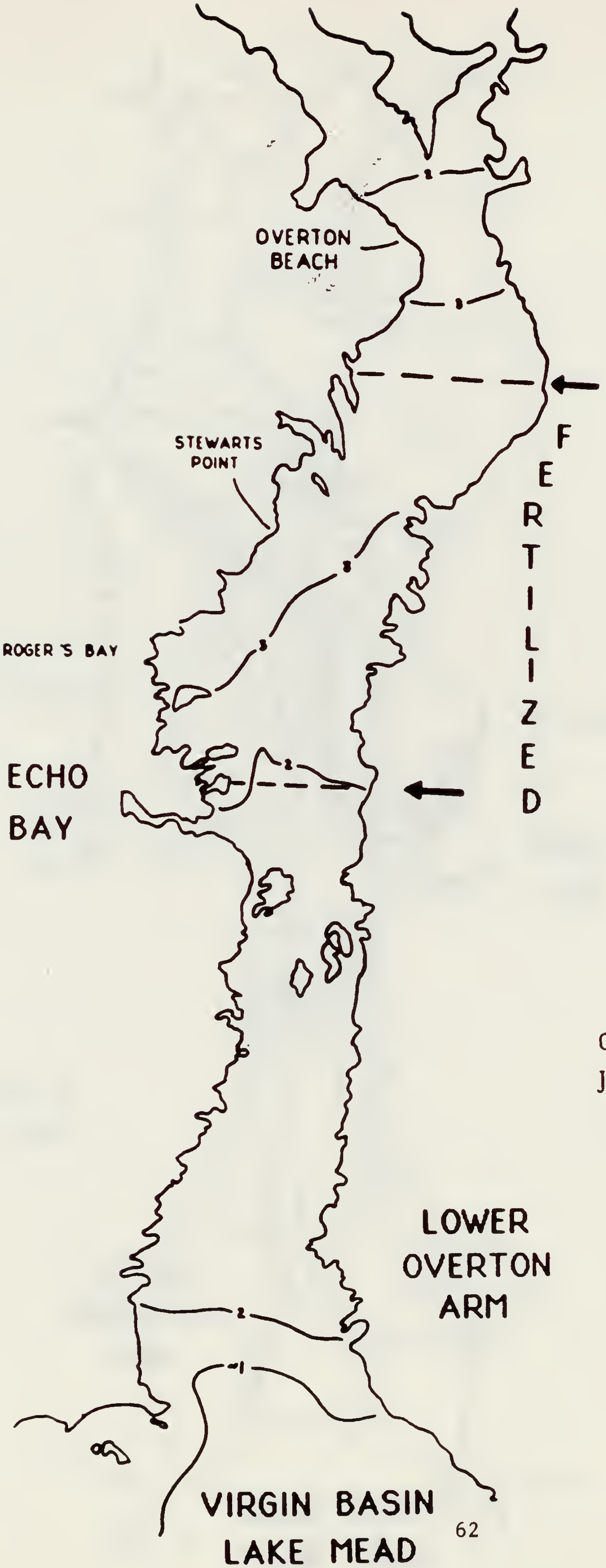
Figure 14 Chlorophyll-a (ug/l) (estimated from chlorophyll fluorescence) isopleths from three synoptic surveys conducted during the Overton Arm Fertilization Project in 1987 Each graph generated from 35-45 discrete values measured for 0-5m vertically integrated composites



A. DAY -3,
May 27, 1987



B. DAY +4.
June 3, 1987



C. DAY +9.
June 8, 1987

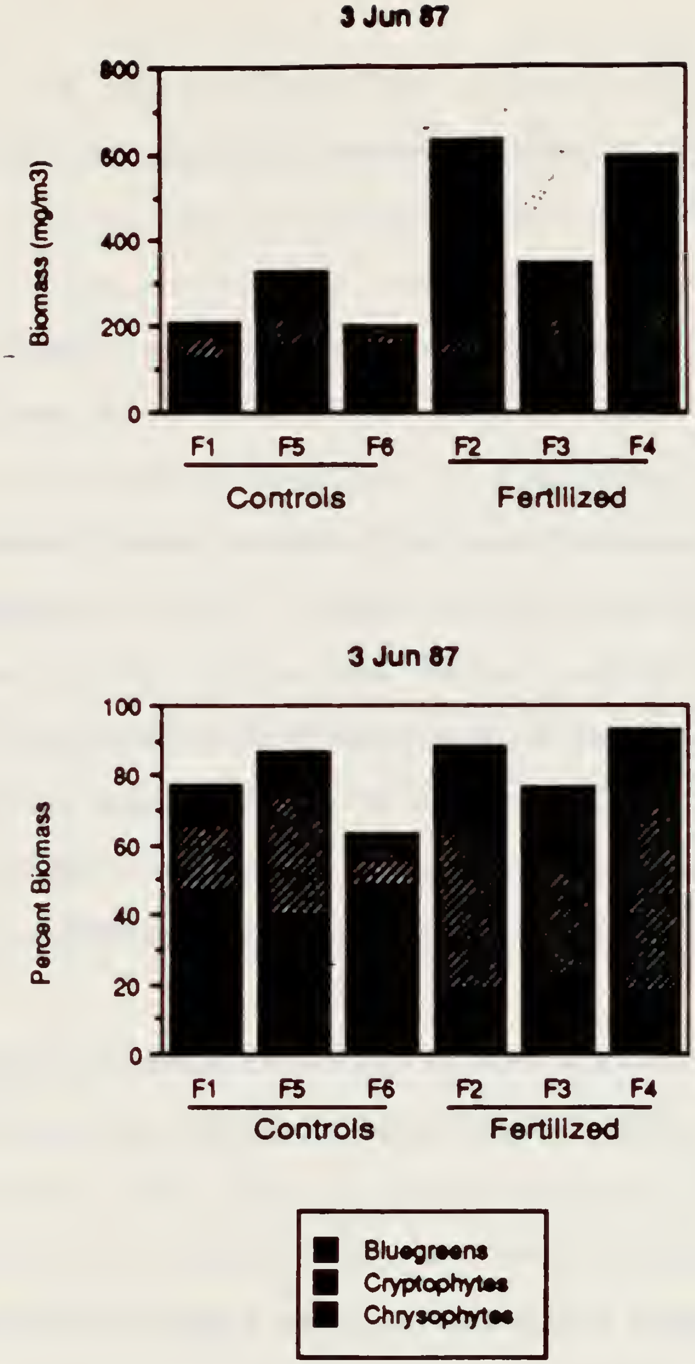


Figure 15. Phytoplankton biomass (upper) and percent biomass (lower) of the most abundant phytoplankton groups in unfertilized (contol) stations and fertilized stations in Lake Mead after fertilization.

1. Algae responded as predicted and increased to mesotrophic levels

2. The increase in chlorophyll-a in the fertilized area was insufficient to cause water quality problems in the fertilized region and was not detectable in the lower Overton Arm. Peak levels of biomass and PPr remained moderate and the response could only be clearly observed for 2-3 weeks. The 30 day chlorophyll-a mean for the fertilization region was only 2.4 ± 1.8 ug/l (x ± s.d.), relative to values of 2.2 ± 0.7 for north control F-1, and 1.7 ± 0.4 for south control F-6. This is well below the 5 ug/l chlorophyll-a standard that was adopted for Lake Mead by the Nevada Environmental Commission in September, 1987.

3. Stations F-2, -3, and -4 in the fertilized area generally tracked each other well, in terms of temporal variations in chlorophyll-a.

4. Station F-6 alone provided the best control for the experiment. Station 5 was "compromised" by areas of relatively high chlorophyll-a, mostly west of the center channel. This probably resulted from surface flow associated with wind-induced seiching around the time of fertilization. It is also possible that some volunteers inadvertently distributed fertilizer in the

area just south of Echo Bay. Station F-1 also showed a small increase in chlorophyll-a during the first week, but this may have been natural, due to the proximity of the site to the Virgin and Muddy River confluence. Water in this region is typically more turbid due to silt from the rivers and from erodible shoreline deposits.

5. Baseline conditions at all stations were reached within about two weeks.

6. Virtually all of the algal biomass increase occurred in the upper 10 meters of the water column.

Algal ^{14}C- Primary Productivity

The results for routine and synoptic measurements of phytoplankton primary productivity (PPr) are presented in Figures 13 and 16. PPr was assayed according to standard ^{14}C-PPr methods (Kellar et al. 1980), but the samples were incubated under fluorescent lights approximating the light and temperature (22°C) in the middle epilimnion (6-8 m).

Although more variable than was biomass, the data clearly indicate a dramatic stimulation to a mesotrophic (moderately productive) state which persisted for a period of about 10 days. We also note, from Figure 16, that a secondary pulse occurred

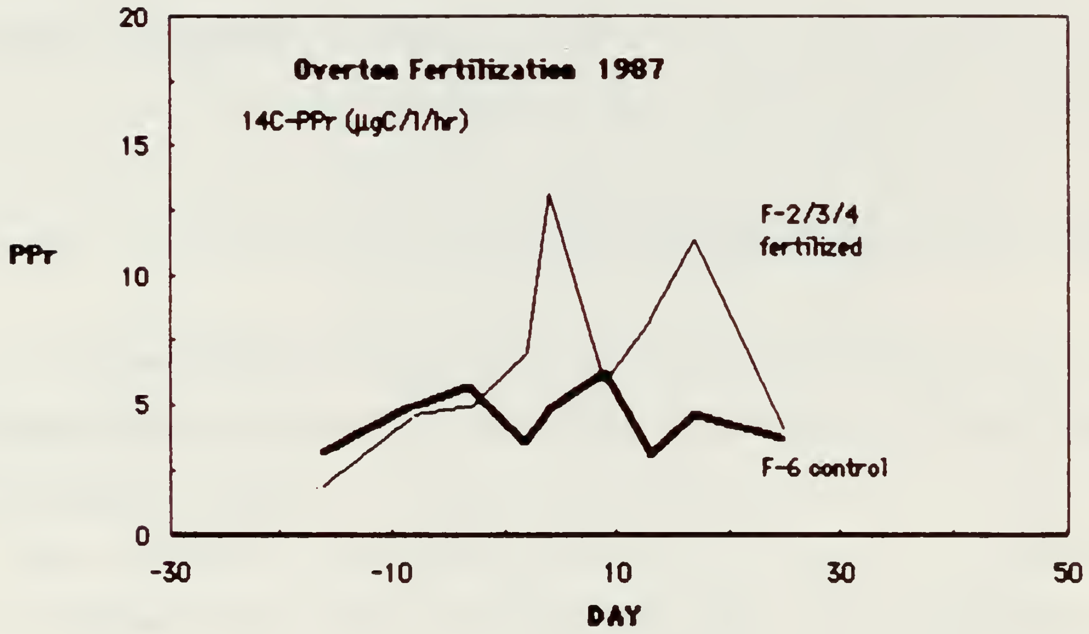


Figure 16 Rates of ^{14}C-primary productivity in 0-5m composite water samples collected during the Overton Arm Fertilization Day 0 = May 30 1987

after about 2 weeks and lasted for about 10 days.

Zooplankton Density, Nutritional Status and Reproductive Rate

Three approaches have been used to evaluate the effects of fertilization on the zooplankton community:

1. Comparison of species-specific densities (and ultimately biomass) at the six fertilization monitoring stations (F-1 to F-6). This data set provides comparisons of pre- and post-fertilization levels in the fertilized region, control stations, and from past years. Full data analysis has not yet been completed.

2. Determinations of growth rates for the major zooplankton species in the fertilized and control areas, before and after fertilization. These analyses are based on life history tables for cohorts identified by size-frequency distributions (Edmondson and Winberg 1971). This study involved intensive sampling at approximately 4 day intervals from May - July 1987 and is currently nearing completion. It will provide estimates of community secondary productivity, in addition to growth rates for cladocerans, copepods and rotifers.

3. Assays of nutritional status of cladocerans based on the

lipid-ovary index and on egg-ratios (Tessier and Goulden 1982, Bjorkman and Shapiro 1986). The data currently available clearly show that numbers, nutritional state and reproductive rate of cladoceran zooplankton were all positively enhanced by the fertilization. A comparison of the densities of the principal cladocerans in the fertilization region (F2/3/4 combined) relative to the south control site (F-6) is shown in Figure 17. Populations of both Daphnia pulex and Daphnia galeata increased dramatically in the first 1-2 weeks following fertilization, immediately after peak chlorophyll-a levels had been attained (see Figure 12). It is important to note that density and biomass responses could be partially masked by shad predation. Therefore, it is possible that the response observed in Figure 17 underestimates the full impact of the fertilization on cladoceran production. The detailed cohort analysis study, when completed, should enable us to better evaluate losses due to predation and natural mortality.

Figure 18 shows lipid droplet indices and the number of eggs per female for Daphnia pulex and Daphnia galeata collected from the middle of the fertilization zone (F-3) and at south control F-6. The lipid assay was initially tested on zooplankton collected along the pronounced fertility gradient from the eutrophic inner Las Vegas Bay to oligotrophic Boulder Basin. The results of this study demonstrated that increased food availablilty would result in higher lipid reserves and egg production in Lake Mead cladocerans (Vaux unpubl.). Previous feeding experiments per-

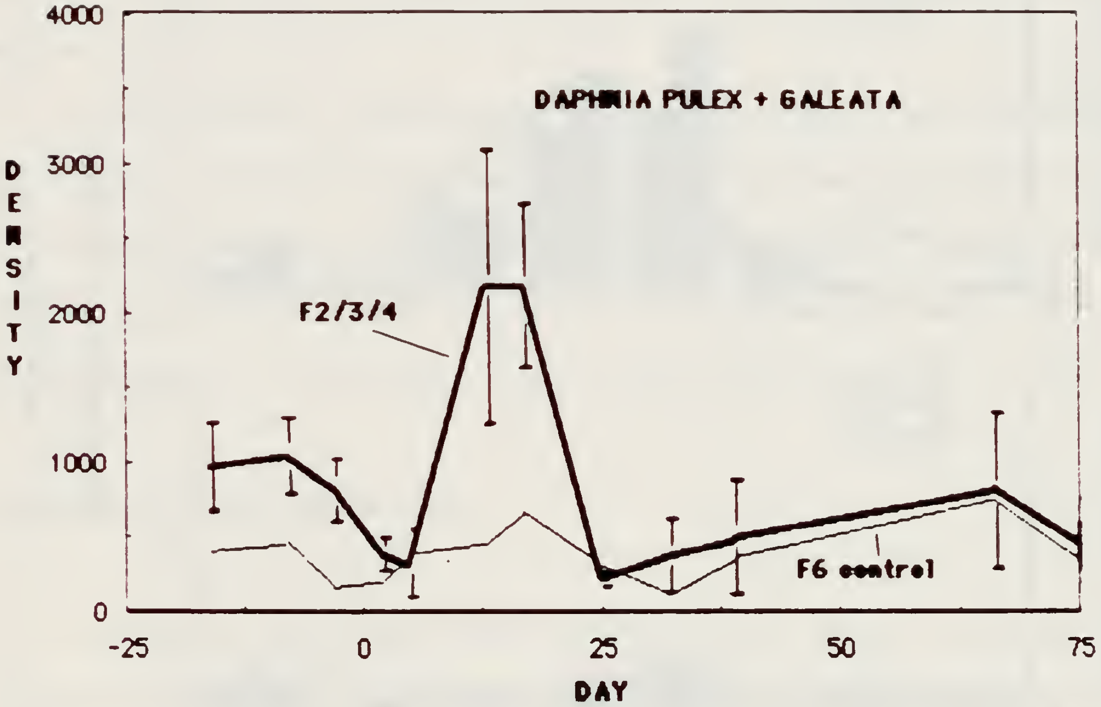


Figure 17. Densities of Daphnia pulex and Daphnia galeata, in #/m^3, for the fertilized region (F-2/3/4 as mean ± s.d.) and the south control station F-6. Day 0 = May 30, 1987

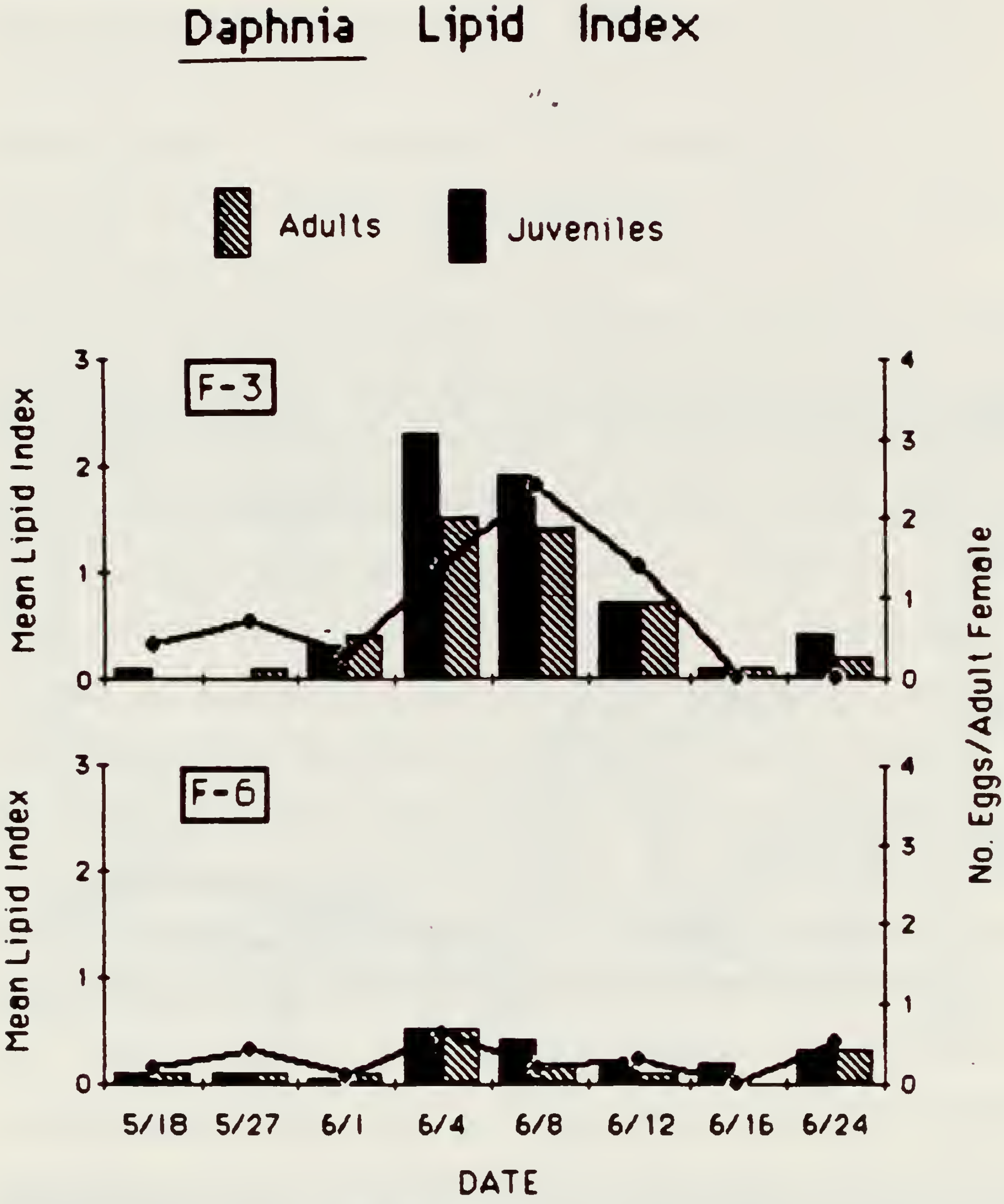


Figure 18. Daphnia lipid droplet indices and egg ratios in the fertilized region (F-3) and in the southern-most control area (F-6).

formed with D. pulex have also showed that animals reared in the more productive waters of the bay have significantly greater rates of growth and reproduction than those from oligotrophic Boulder Basin (Paulson and Baker, 1983a).

Mean lipid index values and egg production increased dramatically between two and five days after fertilization at station F-3, peaked at about the same time as chlorophyll-a, and remained elevated until Day+17 (Figure 18). Values for control station F-6 remained low and exhibited only minor variations throughout the entire data record.

The complete lipid-ovary index data set from mid-May to early July (Day-12 to Day+39) have been plotted against mean chlorophyll-a-fluorescence in Figure 19. It can be seen that improved nutritional status and ovary development were directly correlated with increased food concentrations.

Threadfin Shad Responses

Historically, significant numbers of shad in limnetic areas of the Overton Arm have been largely limited to its extreme northern end, in more productive waters near the Muddy River and Virgin River inflows (Paulson and Baker 1983a, Hutchings 1987).

Echosounding conducted in the fertilized and control areas in May 1987 prior to the fertilization demonstrated low densities of shad throughout the Overton Arm (Figure 20A). It appears that

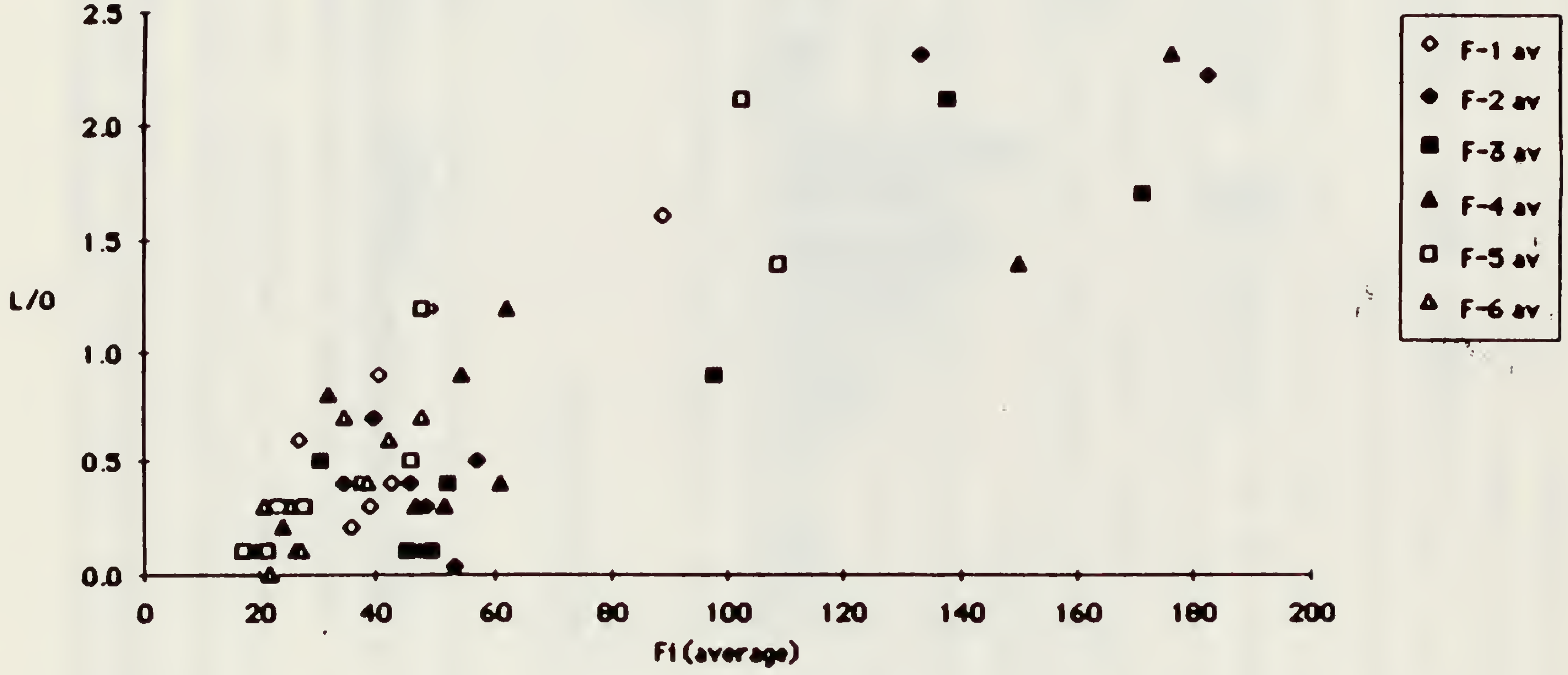


Figure 19. Relationship between mean lipid-ovary index of adult *Daphnia pulex* and chlorophyll fluorescence (F_i). F_i values are averaged over the 4-8 day period prior to zooplankton collection

shad spawned around the time of the fertilization since on June 4, 1987 (Day +5) we noted numerous targets in the upper part of the Overton Arm (F-1) and off Rogers Bay (F-4) (Figure 20B and see Figure 7). Comparable densities were not observed in the lower Overton Arm (Station F-6) at this time or anywhere in the Overton Arm at the same time in 1986 (Figure 20B). By July 1 a few targets were noted in the lower arm (stations F-5 and F-6, Figure 21A) but by this time target densities were dramatically higher in the fertilized region (stations F-2, F-3 and F-4) than even at the northern end of the arm (station F-1). This general pattern persisted for much of the summer (Figure 21B). Sonar targets in the fertilized region were significantly higher than in the other main basins of the lake at this time (Figure 21C). The only areas of the lake where densities were comparable to the fertilized region at this time were Iceberg Canyon (Figure 21C) and the middle and inner Las Vegas Bay (Figure 21D) - areas naturally more productive (Paulson et al. 1980, Paulson and Baker 1983a, 1983b; USBR 1987).

It was not possible to include an intensive program of trawl sampling in the 1987 fertilization project, but a pilot trawling series confirmed the presence of shad in areas with high densities of sonar targets (Table 7). Similar results were found in previous trawling efforts (Allan and Roden 1978; Hutchings, unpub.), and trapping (Paulson and Espinosa 1975).

Preliminary analyses of limnetic larval and junvenile shad diets show that, in June, they were feeding on Daphnia and

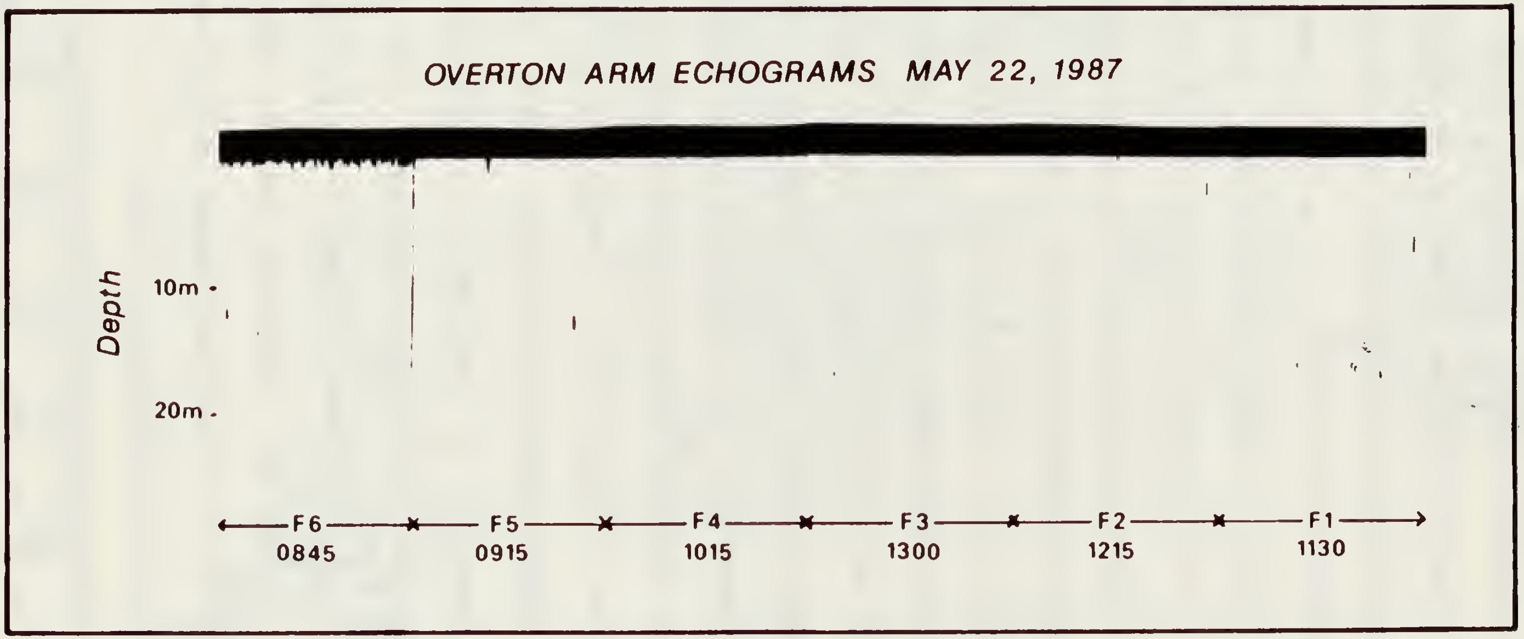


Figure 20a. Echograms from the Overton Arm in May 1987.

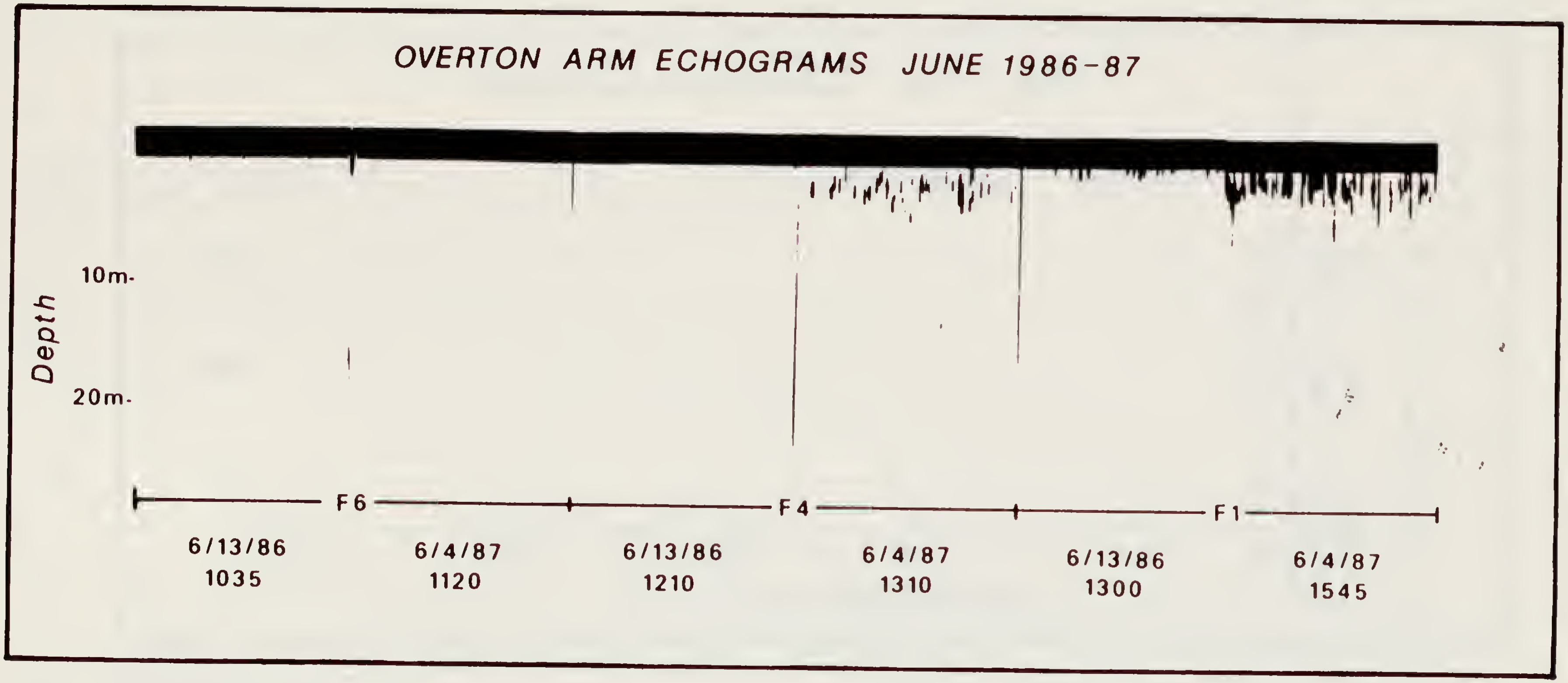


Figure 20b. Echograms from the Overton Arm in June 1986/87.

Figure 21. Lake Mead Echograms in July 1987.

A. Overton Arm, July 1, 1987
B. Overton Arm, July 15, 1987
C. Main Basins and Iceberg Canyon, July 1987
D. Lower Basin, July 23, 1987

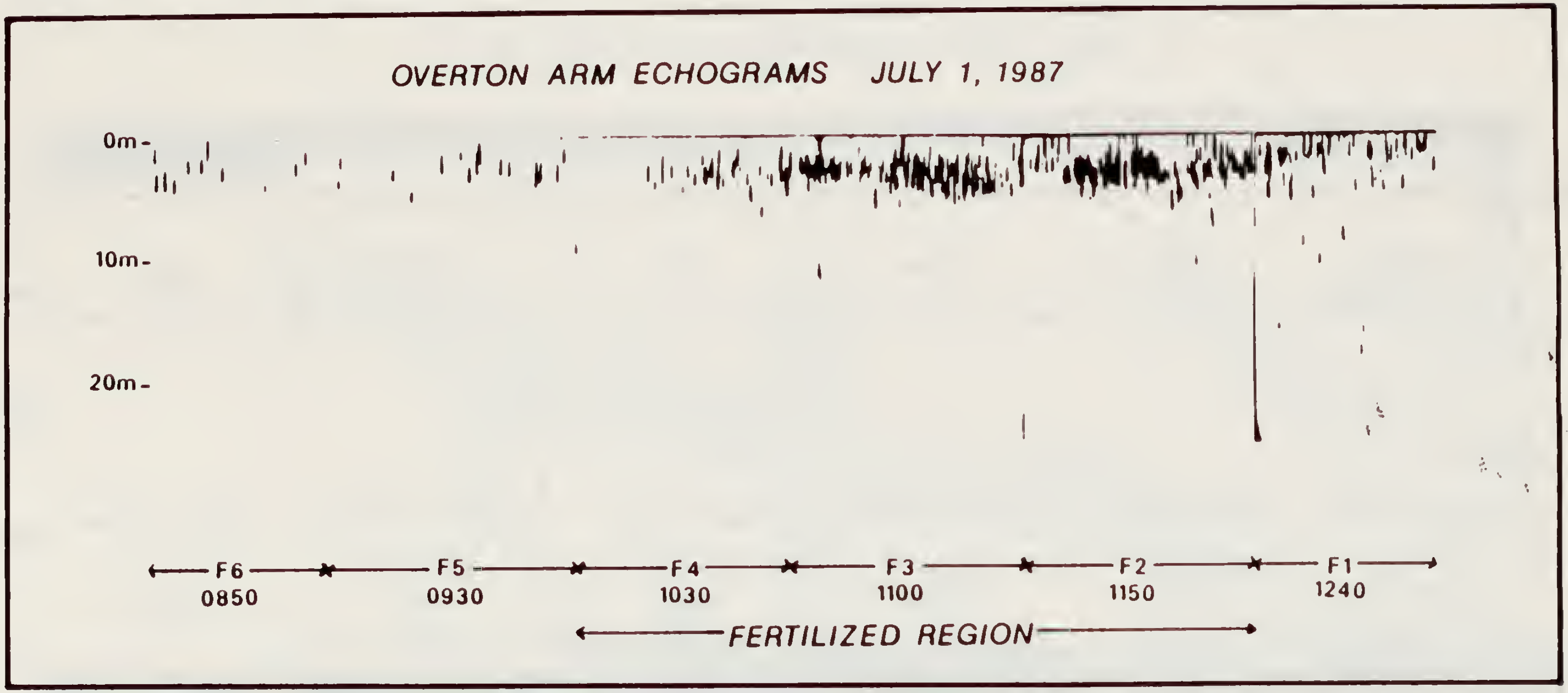

OVERTON ARM ECHOGRAMS JULY 1, 1987
0m-
10m-
20m-
F6
0850
F5
0930
F4
1030
F3
1100
F2
1150
F1
1240
FERTILIZED REGION

Figure 21A.

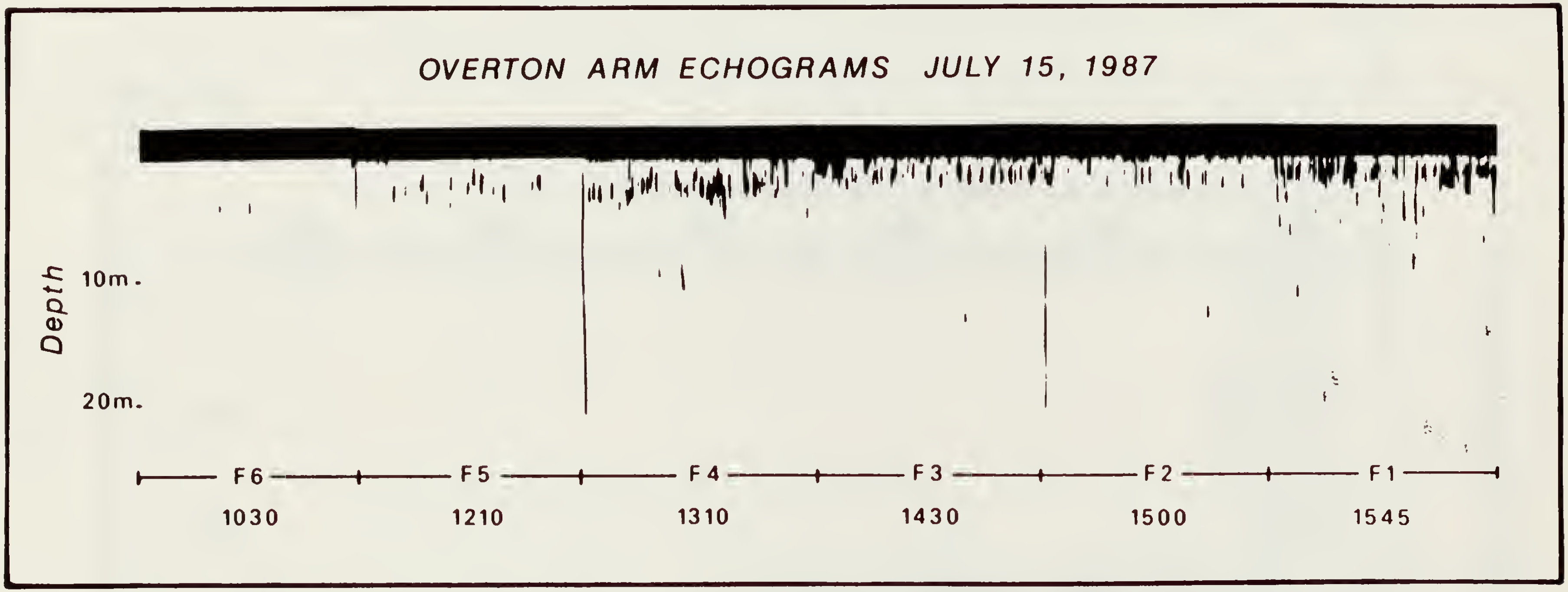

OVERTON ARM ECHOGRAMS JULY 15, 1987
Depth
10m.
20m.
F6
F5
F4
F3
F2
F1
1030
1210
1310
1430
1500
1545

Figure 21B.

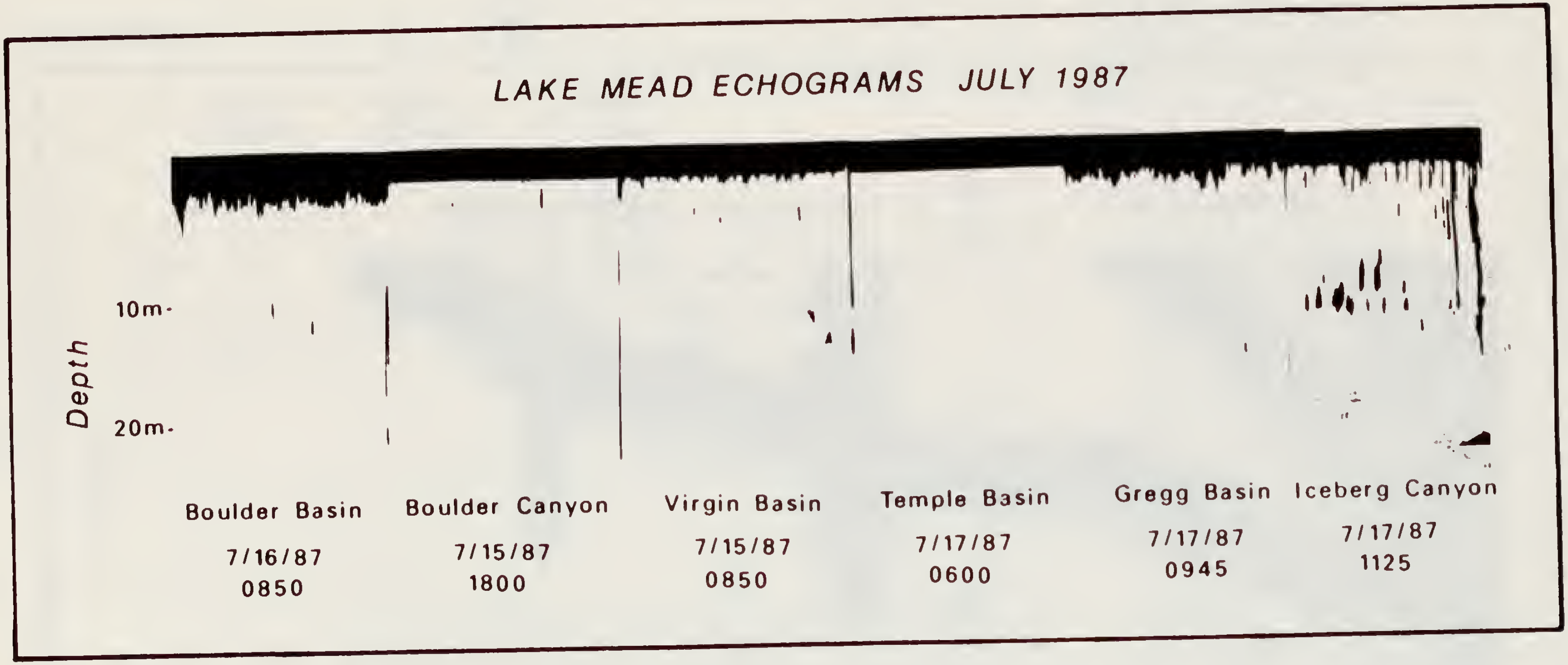

LAKE MEAD ECHOGRAMS JULY 1987
Depth
10m
20m
Boulder Basin
7/16/87
0850
Boulder Canyon
7/15/87
1800
Virgin Basin
7/15/87
0850
Temple Basin
7/17/87
0600
Gregg Basin
7/17/87
0945
Iceberg Canyon
7/17/87
1125

Figure 21C.

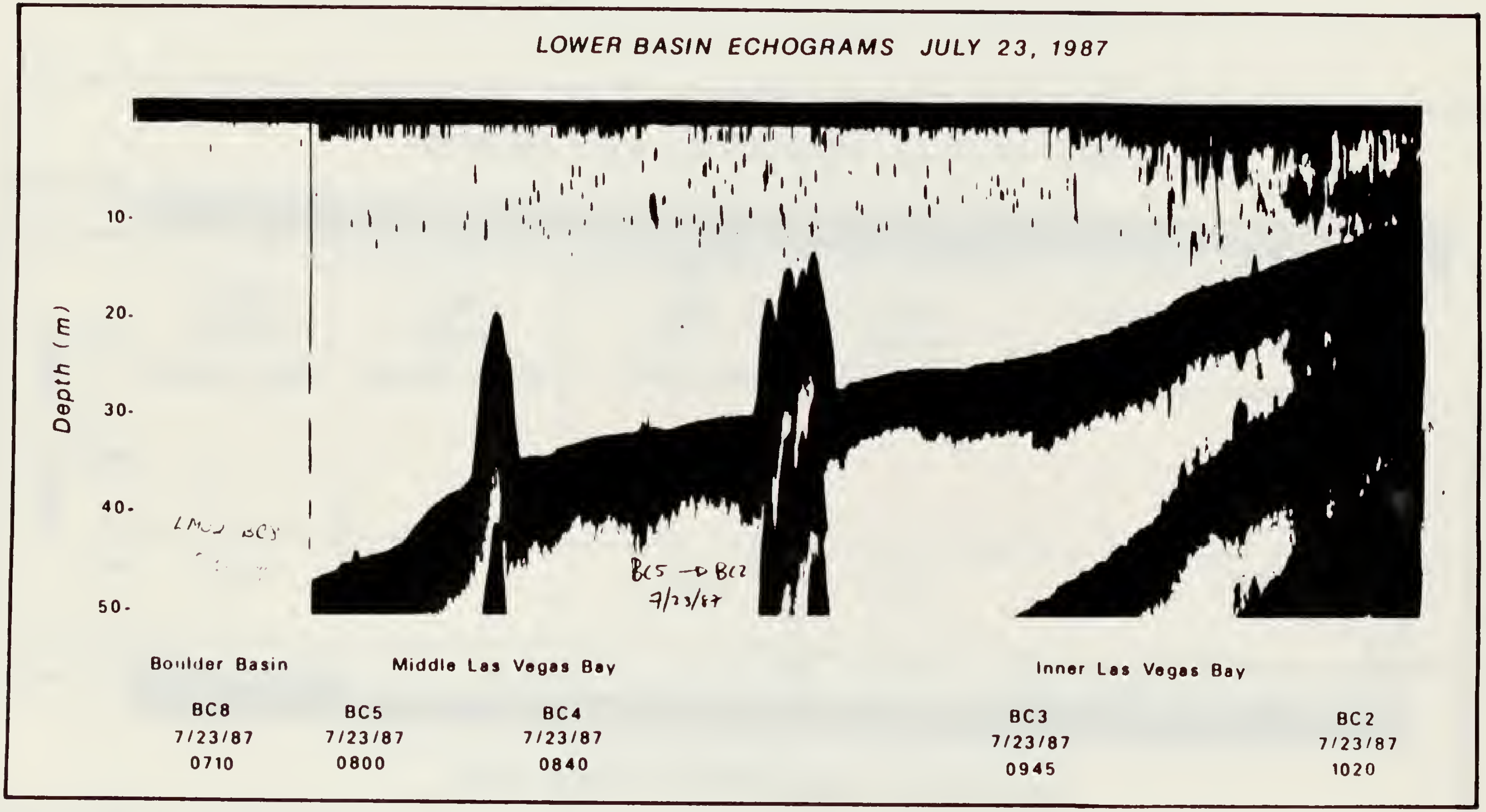

LOWER BASIN ECHOGRAMS JULY 23, 1987
Depth (m)
10
20
30
40
50
BC5 → BC2
7/23/87
Boulder Basin
Middle Las Vegas Bay
Inner Las Vegas Bay
BC8
7/23/87
0710
BC5
7/23/87
0800
BC4
7/23/87
0840
BC3
7/23/87
0945
BC2
7/23/87
1020

Figure 21D.

Table 7. Comparison of numbers and sizes of larval and juvenile threadfin shad caught during pilot trawl sampling in Lake Mead in June 1987 (F1-F6 collections on 6/16/87; other taken on 6/21/87). Standard 3 min trawls at a depth of 1-2 m were made with a 505 um x 1 m diameter ichthyoplankton net. Collections were taken at approximately mid-channel in each sampling region. See Figs. 2, 7 and 21D for station locations. The mean C.V. for a series of 6 replicated hauls taken at various stations in Lake Mead in late June 1987 was 43% (range = 0-94%); mean numbers of shad in each of the 6 sample pairs was 20. (Note that data in this table are from an initial pilot series of trawl samples; they are not the result of a full-scale sampling program -- see text.)

STATION	# SHAD / TRAWL	MEAN T.L. (mm)	LENGTH RANGE (mm)
F-1	166	15	8-21
F-2	487	15	7-27
F-3	82	10	7-24
F-4	36	17	7-23
F-5	12	16	12-20
F-6	3	14	9-20
Boulder Canyon	3	6	4-8
Callville Bay	1	5	-
Boulder Basin	0	-	-
Las Vegas Bay -outer BC5	15	14	5-30
BC4	24	14	5-30
BC3	27	14	7-43
-inner BC2	102	21	9-50

copepodite and adult copepods. By July, Bosmina was the dominant cladoceran in the Overton Arm and this smaller species represented the major item in shad diets.

One hypothesis to explain the apparent increase in shad densities in the fertilized region of the Overton Arm is that the enhanced phytoplankton and zooplankton production following fertilization helped larval shad survive a "food bottleneck" during the first few critical days following hatching (c.f. May 1974). The availability of adequate prey densities has been shown to be an important factor influencing larval survival for a number of fish species (Laurence 1969, Eldridge et al. 1981, Lemly and Dimmick 1982, Li and Mathias 1982, Werner and Blaxter 1980). Mass mortalities of larval shad in some systems may result from failure to begin feeding when zooplankton densities are low (Kilambi and Barger 1975). In addition, Matthews (1984) and Kashuba and Matthews (1984) have documented starvation of shad when zooplankton availability is low. We plan to further address the potential impact that food resources have on shad survival and condition in the Overton Arm of Lake Mead during the proposed 1988 experiment (see Section IV).

Gamefish Responses

When the 1987 fertilization experiment was designed, it was felt that it would be extremely difficult to gauge the success of a first year program on the sport fisheries. Results would likely be confounded by the enormous size of the reservoir, the poor fishing effort and success in the Overton Arm, and the difficulty of ascertaining exactly where a free ranging predator such as a striped bass actually spends most of its time. It was assumed that it would take a number of years before significant improvements in the condition or numbers of game fish could be demonstrated.

However, the apparent population boom of threadfin shad in the fertilization region seems to have attracted tremendous numbers of striped bass. Large schools of surface-feeding striped bass were first observed in mid-July 1987, and "top-water" fishing has remained excellent through December 1987 (Appendix 1). Reports from NPS and NDOW personnel, professional fishing guides and writers, and marina personnel all indicate that this type of activity is new to this region. Furthermore, the condition factors for striped bass caught in the Overton Arm in 1987 were 22% higher than for fish caught in the rest of the lake in 1987, 19% higher than in the Overton Arm prior to fertilization (1984-86), and 28% higher than in the entire lake combined in the period 1984-86 (Figure 22, Table 8).

Available stomach analyses of striped bass creeled from the Overton Arm clearly demonstrate the importance of shad to striper diets. Of the 134 stomachs examined to date, only 19% were empty. All except for one of the stomachs with food contained threadfin

Table 8 . Summary of average condition factors (K, based on forklength) for Lake Mead striped bass. Data for Upper Basin from AGFD creel census except for 1987 as noted. UNLV data for the Overton Arm are for the period July-November 1987. All other values are from NDOW creel records (Hutchings 1987) . NDOW data for 1987 are provisional and include the period through September. ( ) =n, the # of fish in the sample.

	LAS VEGAS BAY	BOULDER BASIN	VIRGIN BASIN	UPPER BASIN	OVERTON ARM	
					NDOW	UNLV
1987:	1.08 (987)	1.06 (459)	1.08 (16)	0.99[1] (260)	1.28[2] (391)	1.29 (546)
1986:	1.06 (140)	1.07 (60)	0.90 (2)	0.85 (809)	1.04[3] (282)	--
1985:	1.05 (66)	1.07 (28)	--	1.03 (182)	1.11[3] (341)	--
1984:	1.10 (178)	1.06 (56)	1.05 (20)	0.89 (512)	1.09[3] (160)	

1 Based on NDOW creel (k=0.99, n=16), AGFD creel (k=0.93, n=171), and AGFD survey (k=1.15, n=73)

2 Includes NDOW zones 4 , 5 , and 8

3 Includes NDOW zones 4 and 5

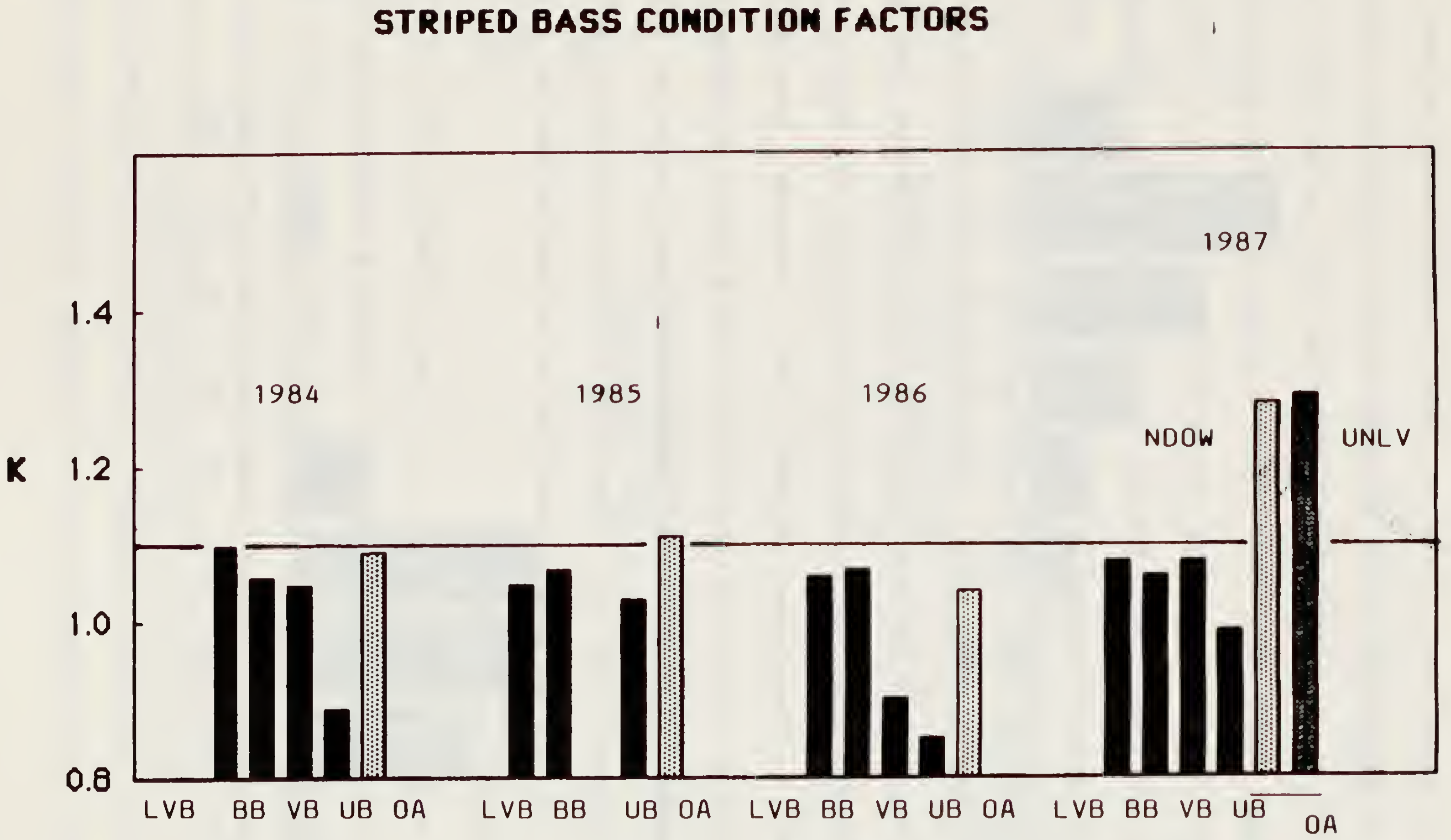


Figure 22. Striped bass condition factors for Lake Mead fish, 1984-1987. LVB=Las Vegas Bay, BB=Boulder Basin, VB=Virgin Basin, UB=Temple and upper basins, OA=Overton Arm. Data sources and numbers of fish averaged for each value are reported in Table 8.

shad. Figure 23 presents size frequency distributions of the shad found in striped bass stomachs (shad lengths were either measured directly or estimated from gizzard weight using the regression of Minckley and Paulson [1976]). Striped bass taken from open water in September 1987 were feeding principally on the 20-50 mm (FL) size class which represents young-of-the-year shad (Deacon et al. 1972, c.f. Johnson 1970, Bryant and Houser 1968). Striped bass taken from inshore areas in November were feeding on larger shad. from the previous year class (Age I) that had presumably been spawned in the Overton Arm. It is unclear if the latter prey size frequency distribution represents active selection for larger fish by the striped bass, or simply the fact that the Age 0 class was not present in the coves at that time. However, the fact that shad were obviously available to stripers (and, presumably, largemouth bass) in cove areas illustrates the potential significance of the proposed 1988 fall cove fertilization whose objective is to increase and maintain shad available to overwintering largemouth bass (see section IV below).

The abundance of shad in striper stomachs and the relatively low percentage of empty stomachs contrasts strongly with recent historical analyses of striped bass food habits in Lake Mead. Persons and Dreyer (1987) found that 49% of striped bass stomachs collected from the Upper Basin of Lake Mead in 1983-84 were empty. Furthermore, shad were present in only 1% of those that did contain food. The frequency of occurrence of shad in striper

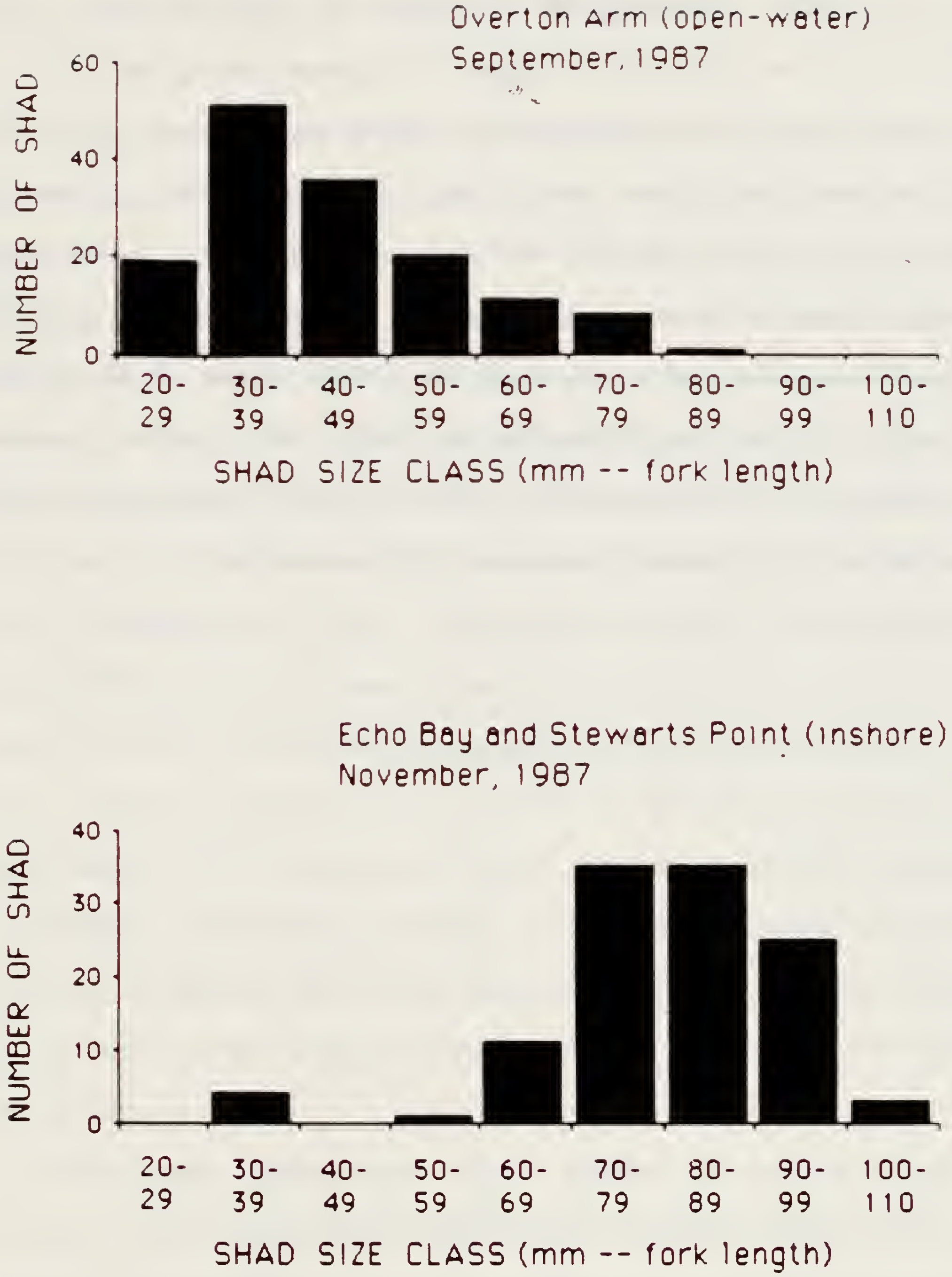


Figure 23. Size frequency distributions of shad recovered from striped bass stomachs in the Overton Arm of Lake Mead. (# of stomachs = 38 and 41 for upper and lower panels, respectively)

stomachs had thus decreased to virtually zero from the moderate levels of 39% and 66% recorded in 1982 and 1981, respectively (Albert and Baker 1983).

Although the data base regarding shad and gamefish distribution, abundance and food habits is limited at present, it is very clear that short-term fishing success for striped bass in the middle to upper Overton Arm has dramatically improved since the fertilization (Appendix 1; J. Hutchings [NDOW], pers. comm.; UNLV staff observations; R. Wiggins [NPS ranger at Echo Bay], pers. comm.; J. Burns [Echo Bay Marina], pers. comm.; numerous local fishermen). Data are not yet available to evaluate fertilization effects on largemouth bass in this region.

III. SIGNIFICANCE OF PROPOSED RESEARCH

The proposed research is the logical "next step" resulting from extensive baseline historical data analyses and numerous laboratory and field studies of the water quality and aquatic ecology of Lake Mead. These studies have clearly documented a severe decline in the sport fisheries from their former nationally renowned state. The Lake Mead ecosystem is the major component within the Lake Mead National Recreation Area (LMNRA), a geographical feature which was specifically created for its potential recreational usage. The sport fishery is a major element of the LMNRA and its dramatic decline is potentially a significant factor in the recreational usage of this National Park Service Unit. Sport fishing is by itself a resource valued at approximately $70 million per year to the economy of the region (Morgensen and Padilla 1982). Therefore, there are tremendous economic impacts which are potentially associated with the decline in harvest rates and/or body size and condition in these fisheries.

The major purpose of the proposed action is to evaluate the potential for controlled nutrient addition (fertilization) to be used as a management tool for enhancing the forage base and quality of the Lake Mead sport fisheries. Lake Mead is a dynamic and artificially created ecosystem. Management of the system is essential, and the accuracy and effectiveness of short and long-term management policies directly depend upon the kinds of data which can only be provided by the monitoring and experimental research program delineated in this proposal.

The "no action" alternative to this research would essentially mean that no significant steps would be taken to develop (or even investigate) this management tool for reversing the trend of declining fisheries in Lake Mead. It would also mean that the extensive data base resulting from the proposed experiments would not be available for making sound management decisions and that the sport fisheries would also be likely to remain in their current impoverished state, or worsen.

The most significant aspects of the research proposed for 1988 are:

1) Fine-tuning our understanding of the nutrient-phytoplankton and phytoplankton-zooplankton links in the Lake Mead food chain by essentially replicating the successful May 1987 experiment.

2) Evaluating an alternative schedule of fertilization (75% of the 1987 amount in May 1988 and the remaining 25% being added ~ 5 weeks later) with the goal of improving the efficiency of nutrient additions (with respect to food for shad) and minimizing fertilizer usage. Within the context of interannual variability of

aquatic ecosystems, the addition of 75% of the 1987 fertilizer load would still provide adequate "replication" of the 1987 experiment.

3) Conducting more detailed studies of the zooplankton-shad, shad-striped bass, and shad-largemouth bass relationships.

4) Developing alternative methodology for introducing fertilizer (using barges) which would be necessary in applications where a volunteer effort is either not possible or inappropriate.

5) Providing a second, detailed set of water quality monitoring data (in addition to the 1987 data) which can be evaluated to ensure that fertilization at the proposed levels is totally compatible with the other beneficial uses of the lake and lakewater.

6) Conduct a pilot experiment in which select coves in the Overton Arm are fertilized in the fall of 1988 with the ultimate objective of sustaining shad abundance and growth in these regions and improving largemouth bass condition and over-winter survival.

7) Further expanding community involvement in the project in order to provide cost-savings in fertilizer application, improve the creel census for sampling game fish, and very importantly - to educate the public. Improved public awareness and understanding

of the Lake Mead ecosystem directly conforms to the current policy goals of the National Park Service and U.S. Bureau of Reclamation and would be an important contribution to the policy/management process.

IV. PROPOSED RESEARCH

A. Overview

The overall objective of the proposed fertilization experiments for 1988 is to provide a "bottom-up" improvement of the food chain by introducing ~ 20 ppb of inorganic phosphorus to stimulate phytoplankton productivity. Increased phytoplankton production will provide additional food resources for food-limited zooplankton. This increase in algal and zooplankton biomass and productivity will result in an improved food spectrum for threadfin shad, the primary forage for game fish in Lake Mead.

The primary goal of the 1988 experiments is, therefore, to continue to evaluate the response of the phytoplankton-zooplankton-shad segment of the food chain to phosphorus addition in a P-deficient region of the lake. Secondary goals include: i) investigating the shad-striped bass and shad-largemouth bass relationships in order to evaluate game fish responses to food-chain enhancement, and ii) to provide additional information on game fish feeding ecology, and nutritional condition.

A major consideration in the evolution of the Lake Mead Fertilization Project has been non-degradation of water quality with no significant adverse impacts on the other beneficial uses of the lake. This consideration was specifically addressed in the Environmental Assessment (EA) for the 1987 Overton Arm Fertilization (which is not substantively different from the proposed 1988 experiments, with regard to nutrient loads). The 1988 monitoring/research program has again been designed to provide a framework for addressing the water quality concerns of the various water user groups, in addition to providing the data needed to scientifically evaluate the food-chain objectives.

The key elements of the proposed 1988 experimental fertilization program are as follows:

- Fertilize 18,950 acres of the Overton Arm to a level of 15 ppb phosphorus in May 1988, using similar methodology and monitoring to the 1987 project (Table 9).

- Re-fertilize the same area to 5 ppb phosphorus in June 1988 to improve the overall transfer efficiency of algal and zooplankton production into shad biomass, relative to the 1987 project.

- Fertilize selected coves of the Overton Arm in fall 1988 with the ultimate objective of improving the condition and over-winter survival of largemouth bass.

Table 9. Fertilizer application schedule for proposed Overton Arm, Lake Mead experiments in 1988. Fertilizer will be liquid ammonium polyphosphate, formulation 10-34-0, "white". See also Figure 7.

EXPERIMENT	SITE(S)	AREA (acres)	DATE	FERTILIZER (gallons)	P-SPIKE (µg P/l)
I	Main Arm	18950	May 21	15000	~15
II	Main Arm	18950	~June 25	5000	~5
III	Coves[1]	~3000	mid-October[2]	3-5000[3]	~20

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[1] We propose to fertilize Salt Bay, Fire Bay, Stewarts Bay, Roger's Bay and Calico Bay. Control coves will include Salt Cove, Glory Hole, Lime Cove, Quail Bay, Cathedral Cove, Catclaw Cove and Miners Cove.

[2] The exact date of cove fertilizations will depend upon the fall mixing characteristics of the lake, and the timing of nitrate appearance in the epilimnion (derived from the hypolimnion).

[3] We will calculate the exact amount of fertilizer needed to obtain an enrichment of 20 µgP/l based upon morphometric surveys of the coves and the thermocline depth

B. Statement of Objectives, Hypotheses and Specific Research Plans (see Section V for specific methodology).

ALGAE

Objective 1: Increase phytoplankton biomass to moderate (mesotrophic) levels by adding liquid ammonium polyphosphate fertilizer.

Hypothesis 1-1: Enrichment of 18,950 acres in the Overton Arm in May 1988 with ~ 15 ugP/l (and an associated +10 ugNH$_3$-N/l) will increase chlorophyll-a levels to 5-10 ug/l for a period of 1-2 weeks after which levels will decline to baseline conditions.

Specific Research Plan 1-1: This hypothesis will be tested in an identical manner to the 1987 Overton experiment (Section II). An intensive limnological monitoring will be carried out in the Overton Arm beginning about a month prior to fertilization. The sampling schedule is summarized in Table 10 and sampling sites depicted in Figure 7.

The six routine sampling stations from 1987 (F-1 to F-6) will again comprise the primary framework for evaluating phytoplankton responses. Data collected from these sites in 1988, together with the 1987 Fertilization Project data set, and previous historical values will provide for comparisons of:

Table 10. Sampling schedule for proposed Spring / Summer 1988 Overton Arm fertilizations. See Figure for sampling locations. W.C. = water column samples at 5-10 discrete depths. 0-5m refers to depth-integrated samples. Schedule assumes fertilizations on May 21, 1988 and ~ June 25, 1988.

PARAMETER DAY	-20	-10	-3	0 May 21	1	3	5	9
PHYSICAL: { T, EC, pH, DO, light }								
F1-F6 (0-30m)	✓	✓	✓	✓	✓			✓
F1,4,6 (bottom)	✓	✓	✓		✓			✓
NUTRIENTS:								
W.C. ● F4, F6			✓		✓			✓
0-5m ● F1-6	✓		✓		✓	✓		✓
0-5m ● VB	✓		✓					✓
CHLOROPHYLL:								
0-5m ● F1-F6	✓	✓	✓		✓	✓	✓	✓
0-5m ● VB	✓		✓					✓
W.C. ● F4, F6			✓			✓		✓
Synoptics in Overton Arm	✓		✓				✓	
PHYTOPLANKTON:								
0-5m ● F1-F6	✓	✓	✓			✓		✓
PHYTOPLANKTON - PPr								
0-5m ● F2/3/4 & F5/6	✓	✓	✓		✓	✓	✓	✓
ZOOPLANKTON:								
0-20m ● F1-F6	✓	✓	✓	✓	✓	✓	✓	✓
0-40m ● F1-F6	✓	✓	✓	✓	✓	✓	✓	✓
SHAD ECHOSOUNDING:	✓	✓	✓	✓	✓	✓	✓	✓
DRINKING WATER STANDARDS:								
Odor ● 0, 50m, VB	✓	✓	✓		✓			
THM ● 0, 50m, VB	✓					✓		

Table 10 . Continued

	13	20	27	34/0 ~ June 25	35	37
PHYSICAL: { T, EC, pH, DO, light }						
F1–F6 (0–30m)		✓	✓	✓	✓	
F1,4,6 (bottom)		✓	✓		✓	
NUTRIENTS:						
V.C. ● F4, F6			✓		✓	
0–5m ● F1–6		✓	✓		✓	✓
0–5m ● VB			✓			
CHLOROPHYLL:						
0–5m ● F1–F6	✓	✓	✓		✓	✓
0–5m ● VB			✓			
V.C. ● F4, F6			✓			✓
Synoptics in Overton Arm	✓		✓			
PHYTOPLANKTON:						
0–5m ● F1–F6	✓	✓	✓		✓	
PHYTOPLANKTON - PPr						
0–5m ● F2/3/4 & F5/6	✓	✓	✓		✓	✓
ZOOPLANKTON:						
0–20m ● F1–F6	✓	✓	✓		✓	
0–40m ● F1–F6	✓	✓	✓		✓	✓
						✓
SHAD ECHOSOUNDING:	✓	✓	✓		✓	✓
DRINKING WATER STANDARDS:						
Odor ● 0, 50m, VB		✓	✓			
THM ● 0, 50m, VB			✓			

PARAMETER DAY	39	43	47	54	61	68	80	110
PHYSICAL: { T,EC, pH, DO, light }								
F1-F6 (0-30m)		✓		✓		✓	✓	✓
F1,4,6 (bottom)		✓		✓		✓	✓	✓
NUTRIENTS:								
W.C. ● F4, F6		✓		✓				
0-5m ● F1-6		✓		✓			✓	✓
0-5m ● VB		✓			✓		✓	✓
CHLOROPHYLL:						✓	✓	✓
0-5m ● F1-F6	✓	✓	✓	✓	✓	✓	✓	✓
0-5m ● VB		✓			✓		✓	✓
W.C. ● F4, F6		✓	✓	✓				
Synoptics in Overton Arm	✓		✓		✓			✓
PHYTOPLANKTON:							✓	✓
0-5m ● F1-F6	✓	✓	✓	✓	✓	✓	✓	✓
PHYTOPLANKTON - PPr								
0-5m ● F2/3/4 & F5/6	✓	✓		✓	✓			
ZOOPLANKTON:								
0-20m ● F1- F6	✓	✓	✓	✓	✓	✓	✓	✓
0-40m ● F1- F6	✓	✓	✓	✓	✓	✓	✓	✓
SHAD ECHOSOUNDING:	✓	✓	✓	✓	✓	✓	✓	✓
DRINKING WATER STANDARDS:								
Odor ● 0, 50m, VB	✓			✓		✓	✓	✓
THM ● 0, 50m, VB				✓			✓	✓

1) Fertilized versus unfertilized areas during the peak response period in 1988,

2) peak response versus pre- and post-fertilization baseline responses in 1988,

3) peak response period in 1988 relative to the peak responses in 1987 and to historical data from the Overton Arm,

4) fertilization region data from 1987 and 1988 relative to all historical data from other oligotrophic regions of Lake Mead.

Intensive synoptic surveys (~50 stations) of chlorophyll-a-fluorescence, using an on-board fluorometer will be performed on days -20, -3, +5, +13 and +27 to determine the spatial variability of algal biomass throughout the Overton Arm and into Virgin Basin. We are also involved in a cooperative effort with the U.S. Bureau of Reclamation to develop a capability for using LANDSAT-5 satellite to remotely sense turbidity and chlorophyll-a in the entire reservoir. May 26, 1988 (Day +5) is a date when LANDSAT-5 can provide total coverage of Lake Mead, and the synoptic cruise scheduled for this date will generate "ground-truth" data for calibrating the satellite instrumentation.

The same type of evaluation will also be performed using the ^{14}C-primary productivity measurements, collected at all six stations.

Hypothesis 1-2: Moderate increases in algal production will be contained within the fertilization region and will not be observable down lake in the Lower Overton Arm, Virgin Basin or Boulder Basin.

Specific Research Plan 1-2: The 1987 data set (section II) showed that fertilization effects on algal biomass and productivity did not extend as far as the lower Overton Arm control station F-6 (Figures 13 and 14). The 1988 sampling program will again include two control stations in the lower Overton Arm (F-5 and F-6), although F-5 will be moved downstream from its 1987 location. The 8 synoptic data sets (Table 10) will further substantiate the results from the routine sampling stations. In addition, we will sample the historical Virgin Basin station (USBR site LM08) at approximately two week intervals throughout the project. Boulder Basin is also sampled on a weekly basis throughout the spring and summer as part of the NDEP's Water Quality Monitoring Program for Las Vegas Bay.

Hypothesis 1-3: The fertilization will primarily stimulate the growth of nanoplankton which is generally considered to be most readily available to zooplankton grazing. Scum-forming blue-green algae (Cyanobacteria) or other noxious forms of algae will not be increased to objectionable levels. Periphyton (attached algae) growth will not be significantly increased in marinas.

Specific Research Plan 1-3: The Cathedral Cove Pre-Fertilization Study and the 1987 Overton Arm Fertilization Project both indicated that nutrient additions primarily increased the growth of nanoplankton and did not create nuisance levels of obnoxious algal species. Quantitative enumerations of phytoplankton from water samples collected at fertilization and control sites will again allow us to evaluate this prediction in 1988.

Periphyton growth (biomass accrual) on unused boats and marina docks and breakwaters will be monitored every 2-3 weeks during the project to determine if nutrient enrichment during jug-filling and loading operations at the Echo Bay Marina significantly increases the amounts of attached algae.

Hypothesis 1-4: Follow-up enrichment of the same 18,950 acre region of the lake with ~ 5 ugP/l (and an associated 3 $ugNH_3$-N/l) approximately 5 weeks after the initial fertilization will provide a secondary pulse of algal growth. We are hypothesizing that splitting the 20 ugP/l enrichment from the 1987 test into a 15 ugP/l and 5 ugP/l spike, ~ 5 weeks apart, will more efficiently transmit algal production into zooplankton production. Maintaining "above-normal" algal levels at two, slightly off-set time periods, will also act to extend the increased food over the time period when shad are hatching.

Specific Research Plan 1-4: This hypothesis is particularly difficult to test because of interannual variability. Since we cannot predict exactly when the main shad span will occur (although we do know that mid-May to mid-June is typical from NDOW observations and historical records), we believe it is prudent to split the fertilization into two "doses". The first addition (May 21) will be at a level of ~15 ugP/l and will essentially replicate the 1987 experiment. The monitoring schedule for phytoplankton and zooplankton characteristics (Table 10) and the research plans for Hypotheses 1-1, 2-1 and 2-2 will enable us to evaluate whether plankton community dynamics in 1988 differ significantly from those in 1987.

The second addition (~25 June) of 5 ugP/l is expected to provide a secondary, although smaller phytoplankton response during a period when algal growth and zooplankton growth and nutritional status have returned to baseline conditions. The proposed sampling schedule has been re-intensified following this addition in order to evaluate whether phytoplankton production can be further increased. Nutrient enrichment bioassays conducted approximately 6 weeks following the 1987 fertilization (baseline conditions) indicated that phytoplankton were still P-deficient, and that sufficient dissolved inorganic-N still was present for phytoplankton growth to be stimulated by P-enrichment (Axler and Vaux, unpubl).

Hypothesis 1-5: Enrichment of selected coves in the Overton Arm in fall 1988 with ~ 20 ugP/l (see Table 9) will increase chlorophyll-a levels to 5-10 ug/l for a period of 1-2 weeks, after which levels will decline to baseline conditions.

Specific Research Plan 1-5: We will characterize algal biomass in the fertilized and control coves before and after fertilization by compositing at least ten samples collected synoptically throughout each cove (Table 11). Each of these ten samples will be vertically integrated from 0-5 m depth. In the larger coves, such at Rogers Bay and Calico Bay, we will also perform discrete analyses of algal biomass from the synoptic stations. Algal biomass will be estimated by both chlorophyll fluorescence and chlorophyll-a extractions.

ZOOPLANKTON

Objective 2: Increase zooplankton growth and reproduction, and improve their nutritional status.

Hypothesis 2-1: Increased algal biomass and primary productivity will result in an improvement in zooplankton production, nutri-

Table 11 Sampling schedule for proposed fall 1988 fertilization of Overton Arm coves

	DAY (fertilization = day 0) 1)							
	-10	-3	+1	+3	+5	+8	+15	+22
Physical 2) (T, EC, pH, DO, light)	✓	✓		✓		✓	✓	✓
Nutrients 3)	✓	✓	✓	✓		✓	✓	✓
Chlorophyll 3)	✓	✓	✓	✓	✓	✓	✓	✓
Phytoplankton 3)		✓		✓		✓		✓
Zooplankton 4)	✓	✓		✓	✓	✓	✓	✓
Echosounder 5) transects	✓	✓		✓		✓	✓	✓

Notes. 1) Sampling schedule is tentative and may be modified on basis of early data returns

2) One profile per cove, taken in mid-point.

3) Samples composited from at least five 0-5m integrated sub-samples taken from various points in each cove.

4) Samples collected by horizontally integrated pumping (see text for more information).

5) See Fig. 24 for electroshocking schedule.

tional status and reproductive rates in the fertilization region relative to unfertilized control areas.

Specific Research Plan 2-1: The impact of increased algal productivity and biomass on the population dynamics and nutritional status of zooplankton will be evaluated with a monitoring program very similar to that established for the 1987 fertilization (section II D). Vertical zooplankton tows will be collected from a series of 7 stations (F1-F6; Virgin Basin) spanning the fertilized and control sections of the Overton Arm using a 64 um-mesh, 30 cm diameter Wisconsin net. Sampling frequency is summarized in Table 10, and is designed to define zooplankton responses to increased algal production following both the May and June fertilizer applications. Using the methodologies described in section V, the samples will be analyzed for species composition, abundance, biomass, developmental stage, size frequency distribution and egg ratio. Data from these analyses will enable a comparison of population trajectories and secondary production between the fertilized and control areas of the Overton Arm. Animals will be indexed for lipid accumulation, ovary development and egg number, parameters which reflect the nutritional status of zooplankton. In 1987, these nutritional assessments were limited to cladocerans, since indexing methodology is well-established only for this group. For the 1988 fertilization, however, we will attempt to extend the lipid-ovary indexing procedure to include copepods.

Hypothesis 2-2: Increased algal biomass following the fall 1988 coves fertilization will stimulate the nutritional state, reproductive rate and population densities of zooplankton in fertilized vs. control coves.

Specific Research Plan 2-2: The impact of the fall fertilization on zooplankton populations in the Overton Arm coves will be assessed by both temporal (before and after fertilizer application) and spatial (fertilized and unfertilized control coves) comparisons of zooplankton abundance, egg production and nutritional status. The sampling program will involve the collection of replicated horizontally integrated pump samples (Edmondson and Winberg 1971) in each of the coves. Sampling will begin one month before the fall fertilization and will continue until the return to "baseline" conditions (Table 11). The use of horizontally integrated samples will counteract the anticipated patchiness of zooplankton in the shallower cove areas, and will also allow the necessary sampling effort to be kept to manageable proportions. Sample analyses will be the same as those carried out on collections from the spring-summer fertilization, with the exception that cohort-based calculations of secondary production will not be undertaken. The focus will be on gross changes in zooplankton densities, nutritional status and reproductive rates (egg ratios).

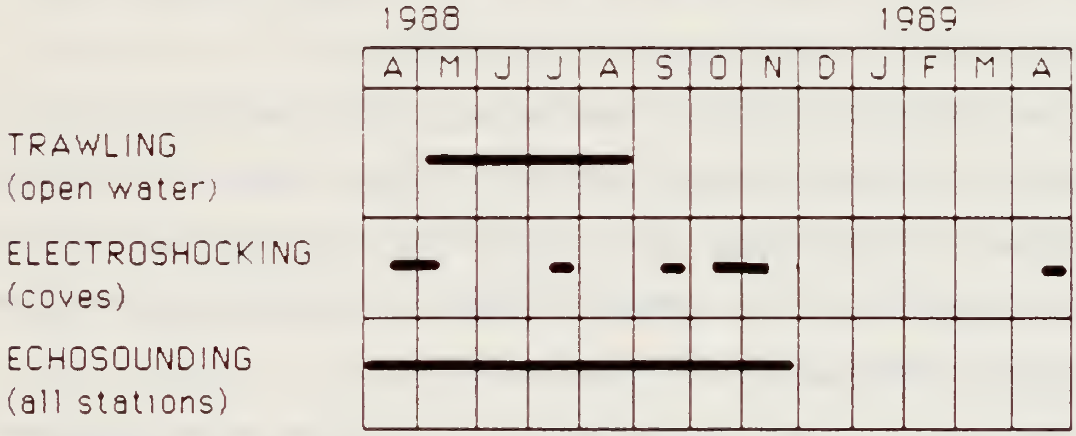
SHAD

Objective 3: Increase the distribution, abundance, and growth rate of threadfin shad in the Overton Arm of Lake Mead.

Hypothesis 3-1: Shad will respond to the increased food resource base (phytoplankton and zooplankton) resulting from the spring/summer fertilizations by increased larval survival (= decreased mortality), increased abundance, and/or improved condition and faster growth rates.

Specific Research Plan 3-1: We will evaluate the responses of threadfin shad by using both population dynamics and "mechanistic" approaches. We will focus on treatment-control area comparisons of the following five parameter sets: abundance, size frequency distribution, short-term growth rates, condition factor, diet and feeding "success".

The primary sampling effort will be aimed at the limnetic (open-water) larval and juvenile shad population. It will consist of horizontal and oblique hauls made with a 1 m diameter ichthyoplankton net and a 1 m^2 Tucker trawl from a set of open-water stations spanning the Overton Arm. Sampling will extend from May (approximate time of first spawn) until at least August, or later



NOTE Bars refer to approximate periods when sampling will be done (see Methods section for more information)

Fig 24 Schedule of fish sampling at pelagic and inshore stations in Overton Arm.

if shad can still be taken with the mid-water trawl at this time (Figure 24). Echosounding transects at the same stations will also be made on a routine basis in order to document horizontal and vertical patterns of relative abundance. These echosounding transects will also allow a comparison of the 1988 fish distribution patterns to the historical data base.

The limnetic sampling program will be supplemented by subsequent electroshocking surveys of littoral areas of the lake in conjunction with the fall cove fertilization (see Hypothesis 3-2, below). Details of the sample collection procedures and schedule are given in Section V and Figure 24.

Temporal and spatial patterns of relative shad abundance will be assessed from a combination of echosounding transects and trawl catch data. There are two principal limitations to these assessment methods. Echosounding (with the equipment currently available) is unable to evaluate absolute fish biomass, and net avoidance will probably become significant once the shad grow larger than about 25 mm (c.f. Matthews 1984). Despite these constraints, however, a comparative assessment of fish abundance (and changes in abundance) in fertilized and control areas of the Overton Arm should be possible during the 3 months following the first fertilizer application. Young-of-the-year shad is the component of the population that is of most interest in terms of the spring/summer fertilization, and the major focus here is on the early history of this age class when individuals will be most susceptible to trawl sampling.

All fish collected will be measured and weighed in order to calculate condition factors and to develop size frequency distributions. Relative feeding "success" will be evaluated with the visceral-somatic index which provides a comparative measure of the amount of food in the gut. This index will be supplemented with microscopic examination of foregut contents from pooled sub-samples of shad larvae and juveniles, in order to compare diets with the available planktonic food assemblage. Condition factor and visceral-somatic index, together, will be compared through time (as the food resource base fluctuates) and through space (between fertilized and control areas of the lake).

Growth rates provide another measure of how the shad respond to the lake fertilization. We will attempt to measure short-term growth rates of larval and juvenile shad by examining otolith microstructure. Many fish species have been shown to form daily growth rings in the otoliths which document growth history since hatching or first feeding (Pannella 1971, Campana and Neilson 1985, Savoy and Crecco 1987, Graham and Townsend 1985). Analysis of otolith microstructure is limited to larval and juvenile fish since the rings become increasingly difficult to distinguish in older fish.

Preliminary analyses of shad larvae collected in 1987 have shown that "daily" rings are present in the Lake Mead population; these analyses will be further developed in 1988. Use of otolith microstructure to measure absolute growth rates requires validation of the initiation and periodicity of ring formation. In this study, the primary interest is in temporal and spatial patterns of relative growth rates, e.g. a comparison of growth rates in fertilized and control areas of the lake over the same time period. We will assume that the initiation and periodicity of ring formation does not vary significantly between stations or with growth rate (e.g. Radtke 1984). Thus full validation of the methodology and a determination of absolute growth rates will not be necessary in this study. Nevertheless, if a strong cohort of larvae is produced (a sharp peak in the size frequency distribution), we anticipate that demonstration of the periodicity of ring formation will be possible by following growth in otoliths and body size for this cohort. This information could be of considerable use in future management-oriented studies of the forage base in Lake Mead. (Section V provides additional details of the analytical approaches summarized here.)

Hypothesis 3-2: Fertilization-induced improvements in food resources in Overton Arm coves in the fall will enhance shad abundance in the coves, and maintain condition in this forage species.

Specific Research Plan 3-2: A monitoring program employing electroshocker sampling in fertilized and control coves will be used to document major impacts of the fall fertilization on fish populations. Section V and Figure 24 provide details of the sampling procedures and schedule for this program.

The relative abundance and size frequency distributions of the cove shad will be assessed from these samples. In addition, their nutritional state will be evaluated using condition factor and the visceral-somatic index. Together, these parameters will document the numerical (attraction to/congregation in coves) and functional (feeding success) responses of shad to fluctuations in the food resource base resulting from the fall fertilizer application.

GAMEFISH

Objective 4: Improve the nutritional condition and increase growth rates of striped bass. Increase the overwinter survival of largemouth bass.

Hypothesis 4-1: Increased availability of threadfin shad in the limnetic and littoral zones will improve the condition factor and growth rate of food-limited striped bass.

Specific Research Plans 4-1: Creel surveys in both the Overton Arm and other areas of Lake Mead will represent the primary method for sampling striped bass and assessing their food habits and condition factor. The creeling effort will be coordinated with NDOW in order to maximize number of fish sampled and area covered. In addition, UNLV will creel their own fish caught with rod and reel. The creel program is a continuing effort by NDOW which will be maintained beyond the life of the experimental fertilization program.

Length and weight will be measured on all sampled fish and stomachs will be collected for subsequent food analyses. Scale samples will also be taken for growth rate determinations. NDOW has an extensive, but as yet unread, scale collection for striped bass (J. Hutchings, personal communication). The possibility of using scales for age and growth determination for striped bass in Lake Mead has been demonstrated (Persons and Dreyer 1987). Selected portions of the historical scale collection will be read in conjunction with 1988 samples, and the data used to assess temporal and lake-wide spatial variations in striped bass growth.

Food habit studies will evaluate the relative importance of different shad year classes in striped bass diets, and the 1988 condition factor data will be compared with the historical data-set covering all major areas of the lake, and also with the 1987 record (Figures 5 and 22).

Hypothesis 4-2: Increased shad availability in the surface waters (epilimnion) of the Overton Arm will result in increased surface feeding ("top-water action") by striped bass and therefore improved fishing success.

Specific Research Plan 4-2: A relative index of fishing success in the Overton Arm will be provided from the creel census data. Catch per unit effort (angler day), total number of fish caught and number of angler-days spent in the Overton Arm will document the quality of the striped bass fishery in this part of Lake Mead.

Hypothesis 4-3: Increased shad availability in near-shore areas, particularly coves, in the spring and fall will improve largemouth bass growth rates and over-winter survival.

Specific Research Plan 4-3: Over-winter survival has already been identified as a critical factor for the Lake Mead largemouth bass population (Morgenson 1983). Threadfin shad were shown to be a major component of largemouth bass diets in Lake Mead when shad were abundant (Deacon et al. 1972; Allan and Roden 1978). The fall cove fertilization is designed to increase shad abundance in the coves (by attraction and/or increased survival) and thus provide an increased forage base for the largemouth bass as they enter the critical winter period. The contribution of these shad to improving largemouth bass condition will be investigated with an electroshocker sampling program in both treated and control coves. Stomach contents of the bass will be analysed and condition factor and visceral-somatic indices compared between sites. Repeat sampling through spring 1989 (Figure 24) will attempt to document temporal changes in relative population density and growth rates in each of the coves. Assessment of survival rates may, however, not prove to be feasible for this initial cove fertilization experiment. Primary emphasis will therefore be placed on documenting effects at the forage biomass (see Hypothesis 3-2) and largemouth bass condition factor levels.

WATER QUALITY AND BENEFICIAL USES

Objective 5: Develop methods for reversing the trend of declining catch for largemouth bass and poor condition of striped bass in Lake Mead which enhance the forage base without adversely impacting the other beneficial uses of the lake.

Hypothesis 5-1: The proposed fertilizations of the Overton Arm will not adversely impact the other beneficial uses of the lake.

Specific Research Plan 5-1: The monitoring schedule and parameter list presented in Table 10 and 11 will enable us to assess the effects of the fertilization on water quality. Routine measurements will be made of the physical (temperature, clarity), chemical (pH, D.O., nitrate + nitrite, ammonium, total-N, ortho-P, total-P, salinity/EC) and biological (algal biomass and species composition) properties of the Overton Arm and Virgin Basin. This information will be combined with a similar data set collected in Boulder Basin and Las Vegas Bay (as part of the NDEP Water Quality Monitoring Program) to evaluate the potential for water quality degradation. We have also added routine measurements of odor and THM's (trihalomethanes) to the parameter list in response to concerns from Nevada, Arizona, and California domestic water suppliers. These frequencies excede those required by the U.S. Environmental Protection Agency and Nevada Division of Environmental Protection for the Southern Nevada Water System - the major supplier of domestic water to the Las Vegas Metropolitan Area (SNWS 1987).

Water samples from the fertilized and control areas will be collected immediately before and after the fertilization for complete anion/cation analyses to further demonstrate that the fertilization cannot significantly affect salinity. This was previously demonstrated in the 1986 PreFertilization Study (Axler et al. 1987) and the 1987 Overton Arm Fertilization Study (see Section II).

It is also noteworthy that the Environmental Assessment for the 1987 experiment (NPS 1987) provides a framework for addressing the beneficial uses of the lake. Based on this assessment, the National Park Service authorized a Finding of No Significant Impact (FONSI) for the 1987 Overton Arm test - which does not differ substantively from the program proposed for 1988. To our knowledge, no new information or technical evaluation has been filed which demonstrates any effects not predicted in this EA.

V. STUDY SITE AND METHODOLOGY

A. Study Site - Lake Mead

Lake Mead is located in the Mojave Desert of southeastern Nevada and northwestern Arizona 15 km northeast of Las Vegas, Nevada. The reservoir was formed in 1935 by construction of Hoover Dam. It extends 183 km from the mouth of the Grand Canyon (Pierce Ferry) to Black Canyon, the site of Hoover Dam (Figure 2). Lake Mead is comprised of four large basins: Boulder, Virgin, Temple and Gregg Basin, interspersed with four narrow canyons: Black, Boulder, Virgin and Iceberg Canyon. The reservoir is bordered by the Muddy and Frenchman Mountains on the north and the Virgin and Black Mountains on the south.

In terms of volume, Lake Mead is the largest reservoir in the country and second only to Lake Powell in surface area. The shoreline is irregular (SLD = 9.7) and includes several large bays (Las Vegas and Bonelli) and numerous coves. The reservoir has a short hydraulic retention rate (3-4 years) due to the great inflow from the Colorado River. The mean depth is 55 m (Table 12). The discharge from Hoover Dam is in the hypolimnion at 83 m depth (at operating level of 364 m).

The prinicpal water inflow to Lake Mead is derived from the Colorado River (90%). The Virgin and Muddy Rivers, which discharge into the Overton Arm, and Las Vegas Wash, which discharges

Table 12. Morphometric characteristics of Lake Mead (Paulson et. al. 1980)

Parameter	Lake Mead
Maximum operating level (m)	374.0
Maximum depth (m)	180.0
Mean depth (m)	55.0
Surface area (km^2)	660.0
Volume ($m^3 \times 10^9$)	36.0
Maximum length (km)	183.0
Maximum width (km)	28.0
Shoreline development*	9.7
Discharge depth (m)	83.0
Annual discharge (1977)($m^3 \times 10^9$)	9.3
Replacement time at maximum operating level (years)	3.9

* Unitless parameter to measure regularity of shoreline, value of 1 is equivalent to a lake shaped in a perfect circle.

into Las Vegas Bay, also contribute year-round inflows. There is only one principal water diversion from Lake Mead. This is located at the Southern Nevada Water Project, Saddle Island (in outer Las Vegas Bay), where municipal, irrigation and industrial waters are diverted to the Las Vegas metropolitan area.

The water quality of the Colorado River and Lake Mead is alkaline (pH 7.6-8.3), and the TDS averages about 550 mg/l. The principal constituents of TDS are the anions sulfate > carbonate > chloride and cations sodium > calcium > magnesium > potassium. Total nitrogen concentrations are moderate (ca. <0.2-0.5 mg/l) but total phosphorus is extremely low (ca. <.010 mg/l) throughout the river. Silica is present in very high quantities (ca. 7-9 mg/l).

The predominant geological features of the Lake Mead floor and surrounding area are the sedimentary deposits of the Muddy Creek formation that were formed during the Paleozoic and Mesozoic eras (Longwell 1936). These deposits consist of moderately consolidated sand, silt and clay. There are also layers of shale, sandstone and limestone interspersed with beds of gypsum, anhydrite and rock salt. Deposition of fine silt material since formation of the reservoir has altered the original floor of Lake Mead. Up to 25 m of silt material was deposited in the upper reaches of the reservoir before Lake Powell was formed in 1963 (Prentki et al. 1981).

The vegetation surrounding Lake Mead is comprised primarily of salt cedar (Tamarix gallica) and creosote bush (Larrea *tridentata*). Emergent macrophytes, such as cattails (*Typha sp*) and sedges (*Scirpus sp*), and submergent macrophytes, such as *Potamogeton pectinatus* (sago pondweed), *P. crispus* (curly leaf pondweed), and *Najas marina* (spiny naiad) were considered to be rare, and occur only in isolated coves prior to 1986. However, a project conducted by the UNLV Limnological Research Center in cooperation with the NDOW in 1986 and 1987 have indicated that aquatic plants are much more prevalent than previously believed. These intensive studies have censused shoreline terrestrial and aquatic communities seasonally, and evaluated factors controlling plant growth, and their value as habitat for fish. The ultimate goal of the studies is to develop methodologies for enhancing these stands of vegetation to improve fish habitat (Haley et al. 1987a,b,c).

The climate is arid with annual precipitation averaging about 8 cm. Mean annual temperature is about 19 •C with a range from 45 •C in the summer down to -1 •C in the winter. Winds are highly variable, but generally, southerly winds prevail in the summer compared to north-easterly winds in the winter.

The Overton Arm covers the former channel of the Virgin and Muddy Rivers, and extends approximately 35 km from the Colorado River channel (Figures 2 and 7). The upper half of the Arm from Echo Bay to about Overton Beach was used for fertilization. More than 90% of the area of the arm thermally stratifies with a typical thermocline depth of 13 meters in late spring/early summer

(Paulson and Baker, 1983a). Morphometric characteristics in relation to the entire lake are presented in Table 2. The fertilized water represents about 12% of the total lake area and about 2.3% of total lake volume.

B. Methodology

1. Application Protocols

Fertilizer applications for the proposed May 1988 experiment in the open-water region of the Overton Arm will be made as in May 1987 (see section II. B. and II. C.). The volunteer effort worked as planned and was cost-effective. Because the June 1988 application will involve only 25% of the 1987 fertilizer load, we will attempt to develop a method involving barges to work out details for use in situations where a volunteer effort is not feasible. The pilot cove-fertilizations proposed for fall 1988 can be easily accomplished with either a relatively small volunteer effort or barges.

We propose to use liquid ammonium polyphosphate (10-34-0, white formulation) for the May, June and fall applications. This is the same formulation that was used for the successful 1987 application. Table 9 provides a detailed summary of the volumes of fertilizer to be added.

2. Water Quality

Analytical methods follow those reported in Kellar et al. (1981) and a brief summary is presented in Table 13. Threshold odor numbers and trihalomethanes (THM's) will be analyzed by the Quality Assurance Laboratory at the Environmental Research Laboratory at UNLV. This laboratory is described in Section VIII (Facilities Available) and is under contract to the U.S.E.P.A. to provide quality assurance/control standards to be used by all EPA contract labs which analyze samples from Super-Fund sites. Major anion/cation concentrations will be either determined by the USBR, Lower Colorado Region Soil and Water Laboratory in Boulder city, NV or the Quality Assurance Laboratory at UNLV.

3. Algae

Algal biomass will be routinely estimated by determining chlorophyll-a concentrations in 90% acetone extracts according to standard methods used by the Lake Mead Limnological Research Center (Kellar et al. 1981). Routine measurements will be made using the 0-5m vertically integrated composites collected for other water quality parameters (see above). Additional estimates of chlorophyll will be made using a Turner-111 fluorometer set up with a red-sensitive photomultiplier, high sensitivity door, blue fluorescent lamp (F4T54B) emitting light through a blue primary

Table 13. Brief summary of analytical prodedures used in the Pre-Fertlizaion Study. Full details and references can be found in the UNLV Lake Mead Limnological Research Center's methods manual (Kellar et al. 1981).

PARAMETER	METHOD
Nitrate + nitrite	hydrazine reduction / NED-sulfanilimide / colorimetry
Ammonia	phenol-hypochlorite / colorimetry
Total nitrogen	persulfate combustion (basic)
Orthophosphate	ascorbic acid- molybdenum blue / colorimetry
Total phosphorus	persulfate combustion (acidic)
Chlorophyll-a	trichromatic equations using 90% acetone extract ; *in vivo* fluorescence after correction for filtrate background fluorescence
Temperature, D.O., pH, EC	Hydrolab Water Quality Analyzer (calibrated daily)
Light intensity	Licor Quantum Sensor (P.A.R.)
Phytoplankton primary productivity (PPr)	short-term radiotracer assays with $H^{14}CO_3$ at constant temperature and light
Alkalinity, DIC	titration with standardized acid
Phytoplankton identification and cell density	microscopy using *Utermohl* settling chambers

filter (CS5-60) and receiving emissions through a red (CS2-64) secondary filter. The instrument is zeroed against deionized water before every treatment set and a treatment composite filtrate measured to correct for non-chlorophyll fluorescence (dissolved organic matter, primarily). Scale conversion factors are directly determined using filtered chlorophyll solutions extracted from grass in 90% acetone. Fluorescence values will also be analyzed using a flow through field fluorometer to provide real-time estimates of algal responses.

Subsamples will also be preserved in Lugol's solution for later cell enumerations using the standard Utermohl technique with an inverted microscope (Kellar et al. 1981).

Carbon-14 uptake rates (to estimate primary productivity) will be measured by incubating 100 ml subsamples of 0-5 m integrated composites with $H^{14}CO_3$ for two hours in an incubator with temperature (~22 °C) and light (~ 80 ueinsteins/m^2/sec) approximating mid-epilimnion values at the time of fertilization. Primary productivity rates are then calculated using DIC concentrations obtained from standard alkalinity titrations (Kellar et al. 1981). The sampling schedule is listed in Tables 10 and 11. The schedule calls for more intensive sampling during the 2-3 week period surrounding the fertilizations in May and June when algae responses are expected to be maximal. Additional synoptic surveys will be conducted throughout the summer to more fully delineate spatial patchiness. In particular, a synoptic is scheduled for May 26, 1988 (Day +5) when this intensive survey can provide ground truth for measurements of surface chlorophyll, temperature and turbidity by the LANDSAT 5 satellite. A similar experiment is planned for late June after the second fertilization.

Periphyton growth on stationary boats (essentially stored in marina slips), docks/slips, and tire breakwaters will be measured one week before and ~2 weeks after fertilization. The 1987 results do not warrant a more intensive survey. Syringe samplers similar to those designed by Loeb (1981) will be used to collect algae from a known and standard area of the substrates. Dry weight (60 •C for 24 hours) will be used as an estimator of total organic matter. If the community appears to contain significant amounts of silt, we will ash these samples @ 475 •C for 4 hours to determine ash-free dry weight (AFDW).

4. Zooplankton

Duplicate 0-40 m zooplankton tows will be taken at intervals of 4-7 days (Table 10) from a series of 7 stations spanning the entire Overton Arm. Subsampling and enumeration will be with methods routinely used in Lake Mead zooplankton studies (Kellar et al. 1981). Cohort identification and estimates of secondary production will be carried out using the methods described in Edmondson and Winberg (1971) and computer programs developed by Dr. Carol Folt of Dartmouth University, N.H.

Lipid-ovary indexing of cladocerans (Daphnia sp) will use the method of Tessier and Goulden (1982), as modified by Bjorkman and Shapiro (1986) for use with formalin-preserved samples. In addition, we will attempt to develop a similar index for adult copepods in order to extend nutritional analyses to the other major biomass component of the Lake Mead zooplankton community.

5. Shad

Two methods will be used for sampling the limnetic shad population. The smallest size classes (< ca. 20 mm TL) will be collected with a 1 m diameter, 505 um mesh, flow-metered conical ichthyoplankton net. Tows with this net will be made horizontally at a depth of approximately 2 m (previous work on Lake Mead has shown that shad are concentrated near the surface at night [Paulson and Espinosa 1975, Allan and Roden 1978]).

Limnetic shad will also be sampled with a 1 m^2 Tucker trawl in a cooperative program with NDOW. Discrete depth and oblique tows will be made; actual depths selected will be based on echosounder traces, but we plan to sample at least three strata. The Tucker trawl will sample a broader range of size classes than the ichthyoplankton net. Replicate tows with both nets will be made along longitudinal transects in the fertilized and control areas of the Overton Arm. Tows will be standardized with respect to duration and boat speed. We propose to collect trawl samples at night on a weekly to biweekly schedule from May through at least August. The exact schedule and amount of effort will be based on observed catch rates and their variance. Decisions on the partitioning of effort between different strata will be based on the method of Houser and Dunn (1967).

In addition to the intensive sampling effort in the Overton Arm, we will also collect trawl samples on a less frequent basis from other areas of the lake. These samples will be used for comparative measures of condition, feeding success and, possibly, growth rates. They will not be used to assess changes in abundance lake-wide.

The cove shad populations will be sampled in a cooperative electroshocking program with NDOW, AGFD and USBR. Replicate runs will be made in each of the treatment and control coves, and runs will be standardized with respect to time and current. Total sampling effort will depend on the observed sample sizes and variance. Although the electroshocking program is oriented primarily towards the fall cove fertilization program, pilot sampling will be carried out in the spring of 1988 to obtain baseline data.

Changes in the relative abundance of various size classes will be calculated from both sets of limnetic trawl samples. Observed changes in abundance through time will be compared between fertilized and control areas of the Overton Arm, and will subsequently be examined in comparison with variations in "physiological" indices (condition factor, visceral-somatic index, gut contents and growth rate), as well as ambient food concentrations.

Catch rates per unit effort will also be used to assess relative abundance of shad in the coves, and variations in their condition will be addressed with the set of physiological indices (excluding short-term growth rates).

All shad collected from both the trawling and electroshocking programs will be weighed, measured and placed on ice and subsequently frozen for later analyses.

The entire alimentary canal will be removed from a subsample of about 20 fish from each collection (depending on total variance, stratification will be made by size class where necessary), and the gut and body weighed separately (wet and dry weights) for determination of visceral-somatic index (weight of alimentary canal/weight of body). An additional subsample will be used for food analysis. Foreguts will be removed from 10 randomly selected fish (stratified according to size class where necessary), and the contents pooled. Contents will be filtered onto a 2.4 cm membrane filter, which is then mounted on a glass slide and cleared with cedar oil. Food items will be enumerated under appropriate magnification and the relative volumes of the items estimated from areal coverage on the slide.

Otoliths (sagittae) will be removed from a representative size range of shad from each trawl collection. They will be mounted on a glass slide and examined for the presence of countable "daily" growth rings. Otolith preparation and analysis will essentially follow methods reviewed by Campana and Neilson (1985), but the exact procedures to be selected will be based on additional trials yet to be undertaken on 1987-collected samples. Full validation of the initiation and periodicity of ring formation is not necessary for the major objectives of this study; this matter is further discussed in section IV (Hypothesis 3-1).

6. Gamefish

Striped bass will be sampled principally by creel cenuses undertaken by both NDOW and UNLV personnel. The creel as operated by NDOW personnel is an existing component of fisheries monitoring on Lake Mead, but will be expanded in 1988 to increase sample size. Largemouth bass occur primarily in the littoral areas of the lake. Cove populations will be sampled by electroshocker in a program which will monitor fertilized and control coves starting in September 1988 and extending through spring 1989. The previous section contains additional details of the electroshocking program. This program is being developed in consultation with NDOW, AGFD and USBR personnel in order to standardize collection methodologies with those which already exist.

Whole fish or stomachs will be preserved in 10% formalin and subsequently analysed for food contents. Food items will be separated, identified, and quantified by volume (water displacement) and enumeration (where appropriate). The size frequency distribution of fish prey items will be documented, either by direct measurement of standard or total lengths, or, in the case of partially digested shad, by estimation of lengths from gizzard weights (Minckley and Paulson 1976).

Relative feeding activity by the cove largemouth bass will be assessed by two measures of gut fullness; first, volume of food in the stomach, and second, the visceral-somatic index (described above for shad).

Scale samples will be collected from both largemouth and striped bass. They will be read using standard methodology.

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VII. KEY PERSONNEL

CURRICULUM VITAE

LARRY J. PAULSON

Director, Limnological Research Center, Environmental Research Center, University of Nevada, Las Vegas.

PERSONAL

Birthdate: November 1, 1945
Citizenship: United States
Marital Status: Married

EDUCATION

Ph.D., University of California, Davis (Ecology-Limnology), 1977
M.S., University of California, Davis (Ecology), 1975
B.S., University of Nevada, Las Vegas (Biology), 1972

PROFESSIONAL EXPERIENCE

July 1985 to Present:

Director, Limnological Research Center, Environmental Research Center, University of Nevada, Las Vegas, Las Vegas, Nevada 89154.

July 1979 to July 1985:

Director, Limnological Research Center, University of Nevada, Las Vegas.

October 1977 to June 1979:

Research Assistant Professor, University of Nevada, Las Vegas.

April 1977 to June 1977:

Instructor, University of California, Davis (Limnology).

June 1976 to September 1977:

Field Director, Castle Lake Limnology Station, Mt. Shasta, California.

March 1974 to September 1977:

Research Assistant, University of California, Davis (Castle Lake Limnological Investigations).

February 1973 to August 1973:

Research Assistant, University of Nevada, Las Vegas (Native Bait Fish Investigations).

December 1971 to January 1973:

Research Associate, University of Nevada, Las Vegas (Lake Mead Water Pollution Investigations).

July 1970 to November 1971:

Research Assistant, University of Nevada, Las Vegas (IBP Desert Biome Studies).

June 1969 to June 1970:

Research Assistant, University of Nevada, Las Vegas (Lake Mead Fisheries Investigations).

CONSULTING EXPERIENCE

Brown and Caldwell Co., Sacramento, CA
City of Las Vegas, NV
Cities of Thornton and Westminster, CO
Culp/Wesner/Culp, Sacramento, CA
Ecological Research Associates, Davis, CA
Montgomery Engineers, Pasadena, CA
Nevada Power Company
Playmate Resort Marinas, Boulder City, NV
Richard P. Arber Associates, Denver, CO

FUNDED RESEARCH

Principal investigator for over $1,500,000 of applied limnological and fisheries research on Lake Mead and other reservoirs on the Colorado River since 1979. Research conducted for U.S. Bureau of Reclamation, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, Office of Water Research and Technology, City of Las Vegas, Clark County, Nevada Department of Wildlife, Nevada Division of Environmental Protection, Four Corners Regional Commission.

AWARDS AND MEMBERSHIPS

Phi Kappa Phi
Sigma Xi
Who's Who in American Colleges and Universities, 1971-1972
University of California, Davis, Jastro Scholarship, 1975
Water Conservationist of the Year (1986) Award, National Wildlife Fed.
American Men and Women of Science
American Institute of Biological Sciences
American Society of Limnological and Oceanography
International Association of Theoretical and Applied Limnology (SIL)
Water Pollution Control Federation

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Paulson, L.J. and J. R. Baker, "Nutrient Interactions Among Reservoirs in the Colorado River System," *In*: H. G. Stefan (ed.). Symposium on Surface Water Impoundments, American Society of Civil Engineers, p. 1647-1656, Minneapolis, Minnesota, June 2-5, 1980.

Baker, J.R. and L. J. Paulson, "Influence of the Las Vegas Wash Density Current on Nutrient Distribution and Phytoplankton Growth in Las Vegas Bay, Lake Mead. *In*: H. G. Stefan (ed.). Symposium on Surface Water Impoundments. American Society of Civil Engineers, p. 1638-1646, Minneapolis, Minnesota , June 2-5, 1980.

Paulson, L.J. and J. R Baker, "The Effects of Impoundments on Salinity in the Colorado River." *In*: V. D. Adams and V. A. Lamarra (eds.), Symposium on the Aquatic Resources Management of the Colorado River Ecosystem, Las Vegas, Nevada, p. 457-474, Ann Arbor Science Publ., November 16-19, 1983.

Evans, T.D. and L. J. Paulson, "The influence of Lake Powell on the Suspended Sediment-Phosphorus Dynamics of the Colorado River Inflow to Lake Mead." In: V. D. Adams and V. A. Lamarra (eds.), Symposium on the Aquatic Resources Management of the Colorado River Ecosystem, Las Vegas, Nevada, p. 57-70, Ann Arbor Science Publ., November 16-19, 1981.

Paulson, L.J., "Use of Hydroelectric Dams to Reduce Evaporation and Salinity in the Colorado River System." In: V. D. Adams and V. A Lamarra (eds.), Symposium on the Aquatic Resources Management of the Colorado River Ecosystem, Las Vegas Nevada, p. 439-456, Ann Arbor Science Publ., November 16-19, 1983.

Prentki, R.T. and L. J. Paulson, "Historical Patterns of Phytoplankton Productivity in Lake Mead." In: V. D. Adams and V. A. Lamarra (eds.), Symposium on the Aquatic Resources Management of the Colorado River Ecosystem, Las Vegas, Nevada, p. 105-124, Ann Arbor Science Publ., November 16-19, 1983.

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Morris, F.A. and L. J. Paulson, "Current Water Quality Trends in the Las Vegas Wash Wetlands." In: V. D. Adams and V. A. Lamarra (eds.), Symposium on the Aquatic Resources Management of the Colorado River Ecosystem, Las Vegas, Nevada, p. 125-138, Ann Arbor Science Publ., November 16-19, 1983.

Paulson, L.J., "Scientific Perspectives on Integrated Aquatic Resources Management of the Colorado River." In: V. D. Adams and V. A. Lamarra (eds.), Symposium on the Aquatic Resources Management of the Colorado River Ecosystem, Las Vegas, Nevada, p. 685-688, Ann Arbor Science Publ., November 16-19, 1981.

Morris, F.A. and L. J. Paulson, "A Desert Wetlands Created by Wastewater Flows: Current Trends and Problems. In: B. Soots and P. Knutson (eds.), Soc. Wetlands Scientist, 3rd Ann. Meeting, 1983.

Lorenz, W.F., G. C. Budd, R. P. Arber, D. J. Kaunisto, and L. J. Paulson, "Factors Affecting Trophic Modeling in Small Reservoirs." J. Water Poll. Control Fed. 1985.

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Bozek, M.A., L.J. Paulson, G.R. Wilde, and J.E. Deacon, "Spawning Characteristics of the Razorback Sucker in Lake Mohave, AZ-NV during 1982-83. Southwest Naturalist (in press) 1986.

PAPERS PRESENTED

Baker, J.R. and L. J. Paulson, "Vettical Distribution of Threadfin Shad in Lake Mead, Nevada." Cal-Neva chapter meetings of American Fisheries Society, Fresno, California, January 30, 1976.

Paulson, L.J. and J. R. Baker, "Nutrient Budget for Lake Mead." Arizona-Nevada Academy of Science, Twenty-Second Annual Meeting, Flagstaff, Arizona, April 14-15, 1978.

Baker, J.R. and L. J. Paulson, "The Las Vegas Wash Density Current in Lake Mead." Arizona-Nevada Academy of Science, Twenty-Second Annual Meeting, Flagstaff, Arizona, April 14-15, 1978.

Paulson, L.J. and J. R. Baker, "Possible Causes for Long-Term Changes in the Nitrate Budget and Concentration in Lake Mead, Arizona-Nevada." American Society of Limnology and Oceanography, Winter Meeting, January 2-5, 1979.

Paulson, L.J. and J. R. Baker, "Factors Regulating Chlorophyll in Las Vegas Bay, Lake Mead." Arizona-Nevada Academy of Science, Twenty-Third Annual Meeting, Tempe, Arizona, April 13-14, 1979.

Hetzel, D.R. and L. J. Paulson, "Annual Changes in Phytoplankton Composition and Abundance in Las Vegas Bay, Lake Mead." Arizona-Nevada Academy of Science, Twenty-Third Annual Meeting, Tempe, Arizona, April 13-14, 1979.

Baker, J.R. and L. J. Paulson, "Nutrient Dynamics of Las Vegas Wash, a Sewage Effluent Stream Discharging into Lake Mead." Arizona-Nevada Academy of Science, Twenty-Third Annual Meeting, Tempe, Arizona, April 13-14, 1979.

Paulson, L.J., "Technological Versus Biological Methods of Wastewater Treatment." Arizona-Nevada Academy of Science, Twenty-Fourth Annual Meeting, Las Vegas, Nevada, April 10-12, 1980.

Paulson, L.J. and J. R. Baker, "Nutrient Interactions Among Reservoirs on the Colorado River." Arizona-Nevada Academy of Science, Twenty-Fourth Annual Meeting, Las Vegas, Nevada, April 10-12, 1980.

Baker, J.R. and L. J. Paulson, "Influence of Las Vegas Wash Density Current on Nutrient Availability and Phytoplankton Growth in Lake Mead." Arizona-Nevada Academy of Science, Twenty-Fourth Annual Meeting, Las Vegas, Nevada, April 10-12, 1980.

Paulson, L.J., "Desert Reservoirs, Hydropower and Limnology." Symposium on Aquatic Ecology of the Deserts, Ecological Society of America, Tucson, Arizona, August 3-8, 1980 (invited paper).

Baker, J.R. and L. J. Paulson, "Metalimnetic Oxygen Depletion in Lake Mead." Ecological Society of America, Tucson, Arizona, August 3-8, 1980.

Paulson, L.J. and J. R. Baker, "Use of Hydroelectric Dams for Nutrient Manipulation of Reservoirs." American Society of Limnology and Oceanography, 43rd Annual Meeting, Knoxville, Tennessee, June 16-19, 1980.

Kellar, P.E., S. A. Paulson, and L. J. Paulson, "Effects of Phosphorus Loading on Alkaline Phosphatase Activity in Lake Mead." American Society of Limnology and Oceanography, 43rd Annual Meeting, Knoxville, Tennessee, June 16-19, 1980.

Paulson, L.J., "Water Quality Management with Hydroelectric Dams on the Colorado River." Symposium on the Water Quality of the Colorado River, Water Pollution Control Federation Conference, Las Vegas, Nevada, September 28 - October 3, 1980.

Paulson, L.J. and J. R. Baker, "Historical and Current Perspectives on the Phosphorus Controversy in Lake Mead." American Society of Limnology and Oceanography, 3rd Winter Meeting, Seattle, Washington, December 27-20, 1980.

Prentki, R.T., L. J. Paulson, and J. R. Baker, "Effects of Upstream Reservoirs: Lake Mead and Lake Powell, a Case History." American Society of Limnology and Oceanography, 3rd Winter Meeting, Seattle, Washington, December 27-30, 1980.

Hetzel, D.R., J. R. Baker, and L. J. Paulson, "Succession of Diatom Assemblages in the Sediments of Las Vegas Bay, Lake Mead." Arizona-Nevada Academy of Science, Twenty-Fifth Annual Meeting, Tucson, Arizona, May 1-2, 1981.

Evans, T.D. and L. J. Paulson, "The Influence of Lake Powell on the Suspended Sediment-Phosphorus Dynamics of the Colorado River Inflow to Lake Mead." Arizona-Nevada Academy of Science, Twenty-Fifth Annual Meeting, Tucson, Arizona, May 1-2, 1981.

Kellar, P.E. and L. J. Paulson, "Alkaline Phosphatase Activity as an Indication of Phosphorus Deficiency in Lake Mead." Arizona-Nevada Academy of Science, Twenty-Fifth Annual Meeting, Tucson, Arizona, May 1-2, 1981.

Baker, J.R. and L. J. Paulson, "Threadfin Shad (*Dorosoma petenense*) in Lake Mead." Arizona-Nevada Academy of Science, Twenty-Fifth Annual Meeting, Tucson, Arizona, May 1-2, 1981.

Paulson, L.J., "Factors Affecting Salinity in the Colorado River." Colorado River Basin Salinity Control Forum, San Diego, California, October 18-20, 1982.

Lorenz, W.F., G. C. Budd, R. P. Arber, D. J. Kaunisto, and L. J. Paulson, "Factors Affecting Trophic Modeling in Small Reservoirs (Standley

Lake, CO)." 58th Annual Conference, Water Poll. Control Fed., Kansas City, Missouri, October 7, 1985.

Wilde, G.R., M. Bozek, and L. J. Paulson, "Factors Contributing to the Success of Razorback Suckers in Lake Mohave, AZ-NV," American Fishery Society, Western Association Meeting, Snowmass, CO, 1985.

Paulson, L.J., "A History of Colorado River Water Use in Southern Nevada; Some Clues for the Future," Water for Nevada in the 21st Century, Nevada Water Conference, Las Vegas, Nevada, February 25-27, 1986.

Paulson, L.J., "Water Supplies in the Colorado River: The Future of Interbasin Water Transfers." Statewide Water Resources Meeting, Wisconsin Department of Conservation and Natural Resources, Mishroot, Wisconsin, March 18-21, 1986.

Wilde, G.R. and L.J. Paulson, "Spatial Heterogeniety in the Limnetic Zooplankton Community of Lake Mead, Arizona-Nevada." Southwestern Association of Naturalists, Annual Meeting, Norman, OK, April 17-19, 1986.

Wilde, G.R. and L.J. Paulson, "Community Structure of the Limnetic Zooplankton Community of Lake Mead, Arizona-Nevada. 7th Annual Meeting, Prairie State Ecology Conclave, LaCygne, KS, April 25-27, 1986.

Paulson, L.J., "The Lake Mead Fertilization Project." Bass Research Foundation Symposium, University of Oklahoma Biological Station, Norman, OK, May 7-8, 1986.

Paulson, L.J., "Recent Changes in Water Quality of Las Vegas Bay," Nevada Water Pollution Control Association Annual Meeting, Laughlin, Nevada, October 22-24, 1986.

Wilde, G.R. and L. J. Paulson, "Empirical Prediction of Zooplankton Density and Community Structure", 48th Midwest Fish and Wildlife Conference, Omaha, Nebraska, December 7-10, 1986.

EXPERT TESTIMONY

Water quality standards for Las Vegas Wash and Lake Mead, Nevada Environmental Commission Public Hearing, Las Vegas, Nevada, August 10, 1978.

Historical changes in water quality in Las Vegas Bay, Lake Mead, Clark County 208 Plan Public Hearing, Las Vegas, Nevada, May 30, 1978.

Effects of low fertility on striped bass fishery in Lake Mead, Colorado River Wildlife Council Meeting, Las Vegas, Nevada, January 11-12, 1981.

Nutrients and productivity in Lake Powell, Lake Mead, Lake Mohave and Lake Havasu during 1981 and 1982, Colorado River Wildlife Council Meeting, Las Vegas, Nevada, April 5-6, 1982.

Effects of decreased phosphorus loading on productivity in Lake Mead, Nevada Environmental Commission Public Hearing, September 9, 1982.

History of flood control operations in Lake Mead, Congressional Investigations on Colorado River Management, House Committee on Interior and Insular Affairs, Needles, California, September 8, 1983.

Scientific perspectives on the 1983 floods in the Colorado River, Congressional Investigations on Colorado River Management, Science and Technology Subcommittee on Investigations and Oversight, Las Vegas, Nevada, October 14, 1983.

Water Quality of the proposed Lake at Las Vegas, U.S. Army Corps of Engineers Public Hearing, Henderson, Nevada, August 7, 1984.

Water availability in the Colorado River system, Colorado River Commission of Nevada Public Hearing, Las Vegas, Nevada, November 9, 1984.

Recent changes in water quality in Lake Mead, Clark County Commission Meeting, Las Vegas, Nevada, November 6, 1984.

Testimony for Nevada Power Company, District Court, Clark County, State of Nevada, November 7, 1984.

Phosphorus standards for the Virgin and Muddy rivers and Lake Mead, Nevada Environmental Commission Public Hearing, Las Vegas, Nevada, January 15, 1985.

Testimony for city of Westminster et al. vs. City of Golden (Coors) regarding water quality and water rights in Standley Lake, Colorado, Colorado District Court, Weld County, State of Colorado, April 11, 1985.

TECHNICAL REPORTS

Deacon, J.E., L. J. Paulson, and C. O. Minckley, "Effects of Las Vegas Wash Effluents on Bass and Other Gamefish Reproduction and Success," Univ. Nevada, Las Vegas, Dingell Johnson Project No. Nev. F20, Segment 6, Job Completion Report to Nevada Department of Fish and Game, pp. 68, 1970.

Goldman, C.R., A. D. Jassby, L. J. Paulson, B. L. Kimmel, and J. T. Rybock, "A Review of the Limnology and Water Quality Standards for Lake Mead," Ecological Research Assoc., Davis, California, Final Report to Clark County Sanitation Dist. No. 1, pp. 101, 1976.

Baker, J.R., J. E. Deacon, L. J. Paulson, T. A. Burke, S. S. Egdorf, and R. W. Tew, "Limnological Aspects of Lake Mead, Nevada-Arizona," Bureau of Reclamation Rept. No. REC-ERC-77-9, pp. 83, 1977.

Miller, T., L.J. Paulson, J. R. Baker, and J. E. Deacon, "A Survey of Biological Literature on Lake Mohave Related to Potential Impacts of Dredging Black Canyon," Univ. Nevada, Las Vegas, Progress Report to U. S. Bureau of Reclamation, pp. 22, 1979.

Paulson, L.J., "The Limnological Status of Lake Mead and Lake Mohave Under Present and Future Powerplant Operations at Hoover Dam," Lake Mead Limnological Research Center, Tech. Rept. No. 1, Univ. of Nevada, Las Vegas, pp. 229, 1980.

Miller, T.G., L. J. Paulson, and J. R. Baker, "The Influence of Dredging and High Discharge on the Ecology of Black Canyon," Lake Mead Limnological Research Center, Techn. Rept. No. 2, Univ. Nevada, Las Vegas, pp. 59, 1980.

Baker, J.R. and L. J. Paulson, "Evaluation of Possible Temperature Fluctuations from Proposed Power Modifications at Hoover Dam," Lake Mead Limnological Research Center, Tech. Rept. No. 3, Univ. Nevada, Las Vegas, pp. 23, 1980.

Baker, J.R. and L. J. Paulson, "Evaluation of Impacts Associated with Re-regulation of Water Levels in Lake Mohave," Lake Mead Limnological Research Center, Tech. Rept. No. 4, Univ. Nevada, Las Vegas, pp. 28, 1980.

Kellar, P.E., S. A. Paulson, and L. J. Paulson, "Methods for Biological and Chemical Analyses in Reservoirs," Lake Mead Limnological Research Center, Tech. Rept. No. 5, Univ. Nevada, Las Vegas, pp. 234, 1980.

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Haley, J.S., K.O. Wirtz, S. Leavitt, L.J. Paulson, D.H. Baepler, "Wildlife Agency Efforts to Improve Fish Habitats by Introducing Artificial and Natural Cover." Lake Mead Limnological Research Center, Tech. Rept. No. 15, University of Nevada-Las Vegas, pp. 34, 1986.

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CURRICULUM VITAE

RICHARD P. AXLER

Environmental (Aquatic) Biologist

EDUCATION

Ph.D.	1979	Ecology/Limnology, University of California, Davis, California
B.A.	1970	Physics, Temple University, Philadelphia, Pennsylvania

PROFESSIONAL EXPERIENCE

1986 to Present:

Assistant Director, Division of Limnological Research, Environmental Research Center, University of Nevada, Las Vegas, Nevada, 89154.

o Project manager, Lake Mead Pre-Fertilization and Fertilization Studies. Co-designed and co-directed the first Lake Mead Fertilization Project in May/June 1987. This experiment involved coordinating a 1000-person volunteer effort to disperse fertilizer over 20,000 acres of Lake Mead to stimulate the aquatic food chain. This is the largest experiment of its kind ever attempted on a single lake. Designed and directed laboratory and field studies to assess the feasibility of large-scale nutrient enhancement for reversing the trend of declining fisheries in the largest (volumetrically) reservoir in the U. S. (USBR funded). The project has involved conducting two pilot-scale field experiments in a 30-acre cove of Lake Mead, preparing an Environmental Assessment for conducting the 20,000-acre fertilization experiment in Spring, 1987 and developing application and monitoring protocols for the large scale experiment. Additional duties have included participation in the Lakes Mead/Mohave/Havasu Monitoring Program (USBR), Lake Mead Cover Enhancement Project (Nevada Department of Wildlife funded) and the Lake Mead Benthos Project (NOAA funded). Also participated in the teaching of a lab/lecture/ field course in Limnology (UNLV, Fall 1986) and have made numerous presentations to technical and non-technical groups involved or interested in the fertilization project.

1979 to 1986:

Staff Research Scientist, Institute of Ecology and Division of Environmental Studies, University of California, Davis, California, 95616.

o Project Manager, McLauglin Gold Mine-Davis Creek Reservoir Study, 1984 to 1986. Designed and directed a monitoring program to provide management guidance and environmental impact assessment for Yolo County, the State of California and Homestake Mining Company regarding the water supply for one of the largest open-pit gold mines in North America.

- Co-Director, Interagency Tahoe Monitoring Program, 1982 to 1984. Water quality monitoring of Lake Tahoe, Cal-Nev and Tahoe Basin tributaries. More than a dozen local, state and federal agencies participate in this program. Responsible for contract coordination, research planning, field and laboratory direction of 7-10 technical personnel, data analysis and preparation of all reports.

- Project Manager, Tahoe Basin Atmospheric Deposition Study, 1983 to 1984. Directed a study of acid and nutrient loading from atmospheric deposition.

- Field Director, Research Coordinator, Castle Lake Research Program, 1977 to 1983. National Science Foundation Funding. Conducted experimental, process oriented studies of primary production and nutrient recycling in western, mountain lakes. Primary responsibility for preparing grant proposals, progress reports, field station maintenance and assisting with graduate student guidance.

- Teaching Fellow and Lecturer, 1979 and 1983. Taught lecture/laboratory/field course in Limnology. Delivered guest lectures in several Environmental Studies courses every year since 1978.

1984 to 1985:

Contractor-Ecotoxicology, Ecotoxicology Group, Division of Biological Sciences, National Research Council of Canada, Ottawa, Ontario, Canada, 1984 to 1985.

- Established a functional ecotoxicology laboratory in which chemical and radioisotope analyses, microbial rate measurements and microcosm experiments could be conducted.

- Developed generic microcosm test protocols for screening environmental impacts due to toxicants and assessing ecological hazard and risk.

1978 to Present:

Consulting Scientist, to Ecological Research Associates, Davis, California, 1978 to present. Served as a Senior Scientist or Project Manager for more than 20 projects involving environmental issues. Examples include:

- Provided reservoir management advice and critical review of lake/stream monitoring data to Yolo County, California for use in the planning and permitting process for the McLaughlin Gold Mine, 1984 to 1987.

- Synthesized historical data and developed conceptual models of aquatic and terrestrial ecosystems for the Presidentially mandated 1982 Lake Tahoe Environmental Thresholds Study (Tahoe Regional Planning Agency/Brown and Caldwell Consulting Engineers), 1982-1983.

- Evaluated artificial lake designs and water quality in five lakes in Shoreline Regional Park, Mountain View, California. Developed a monitoring program which included priority pollutants to provide early warning in case of leachate intrusion from an adjacent municipal landfill.

Recommended management methods to mitigate against algal blooms while maintaining cost savings by using reclaimed water and nutrients to irrigate a municipal park, 1981 to 1984.

- Conducted microcosm and mesocosm experiments to assess the effects of nutrient discharges from secondary and tertiary treated domestic wastewater on water quality in Las Vegas Bay, Lake Mead, Nevada. EPA funded and coordinated by Brown and Caldwell Consulting Engineers, Inc., 1980 to 1981.

- Assessed the impacts of sediment dredging on water quality in a municipal water supply reservoir. Gibraltar Lake, Santa Barbara, California, 1980 to 1981.

- Provided technical advisory review of research projects utilizing artificial wetlands to remove inorganic and organic pollutants from wastewater at the Santee Facility of the San Diego Region Water Reclamation Agency, California, 1980 to present.

- Provided consultation regarding the design and/or management of recreational artificial lakes for homeowner's associations, engineering companies, environmental planners and municipalities, six projects, 1979 to 1985.

1982 to Present:

Consulting Scientist, to Aquagene Tech. Ltd., San Diego, California. This is a small company involved in applying recent advances in biotechnology to monitor and mitigate the impacts of chemical toxicants.

1975 to 1979:

Dissertation Graduate Research, Ecology Graduate Group, Division of Environmental Studies, University of California, Davis, California.

- Conducted field and laboratory studies of the dynamics of inorganic nitrogen cycling in subalpine, oligotrophic Castle Lake, California. Isotope tracer techniques with radioactive N-13 (10 minute half-life) and stable N-15 labelled nitrate and ammonium were used to directly measure the kinetics of microbial N-uptake. Additional nutrient enrichment experiments and physiological assays utilized measurements of short and long term uptake of C-14 labelled carbon dioxide. Conceptual models were developed and contrasted with marine models.

- Participated in concurrent research studies involving food web dynamics and nutrient transformations in subalpine lakes, including Lake Tahoe, Cal-Nev and Crater Lake, Oregon.

- Maintained a remote mountain laboratory facility for year-round studies and participated in the field and analytical aspects of an intensive, long-term limnological monitoring program.

1970 to 1974:

Research Technician, Department of Physics, Temple University, Philadelphia, Pennsylvania and Penn-Princeton Accelerator Cyclotron Facility Princeton, New Jersey.

- Developed skills in machine shop tooling, high vacuum technology, electronics and low level signal instrumentation, computer programming and laboratory management.

PROFESSIONAL AFFILIATIONS, SPECIAL PRESENTATIONS AND AWARDS

- American Association for the Advancement of Science (AAAS)
- American Society of Limnology and Oceanography (ASLO)
- International Society for Limnology (SIL)
- Water Pollution Control Federation (WPCF)
- North American Lake Management Society (NALMS)
- Sigma Xi
- Member, Crater Lake National Park (Oregon) Scientific Advisory Panel (1982 to 1985)
- Technical Advisor, Task Committee on Aquatic Habitat and Sediment Transport, American Society Civil Engineers (1985 to Present)
- Panel Member, Research Coordinating Committee on the Fate of Agrochemical Residues in Food and the Environment (United Nations FAO/IAEA, 1980 to 1983)
- Grant proposal reviewer for the National Science Foundation
- Manuscript reviewer for Limnology and Oceanography
- Regents Fellowship, University of California
- Jastro-Shields Scholarship

PUBLICATIONS

Fote, A., R. P. Axler, H. K. Schurmann and T. Mihalisin. 1973. Thermo-electric power of Chromium below the Neel temperature. Phys. Rev. B. 8:2099-2105.

Kimmel, B. L., R. P. Axler and C. R. Goldman. 1977. A closing replicate sample sediment trap. Limnol. Oceanography. 22:789-793.

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Axler, R. P., R. M. Gersberg and L. J. Paulson. 1978. Primary productivity in Big Soda Lake, Nevada. Great Basin Nat. 38:187-192.

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Year 1981. Tahoe Research Group, Institute of Ecology, University of California, Davis, 193 p.

Axler, R. P., C. R. Goldman, J. E. Reuter, S. L. Loeb, J. C. Priscu and R. G. Carlton. 1983. Comparative studies of the nitrogen metabolism of phytoplankton and periphyton in oligotrophic lakes. In: Proc. Combined FAO/IAEA Internat. Symp. on the Fate of Agrochemical Residues in Food and the Environment. Rome, Italy, June 1982. IAEA TECDOC 283.

Axler, R., E. Byron, R. Leonard and C. Goldman. 1983. Interagency Tahoe Monitoring Program: Third Annual Report, Water Year 1982. Institute of Ecology, University of California, Davis, 121 p.

Axler, R., E. Byron, R. Leonard and C. Goldman. 1983. Interagency Tahoe Monitoring Program: Atmospheric Deposition of Nutrients in the Lake Tahoe Basin, Water Year 1982. Institute of Ecology, University of California, Davis, 53 p.

Axler, R., J. Reuter, J. Priscu, S. Loeb, R. Carlton, J. Zehr and C. Goldman. 1984. Transformations of nitrogen following epilimnetic N-fertilization in Castle Lake, California. 2. Nitrate and ammonium depletion pathways. Verh. Internat. Verein. Limnol. 22:583.

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Reuter, J. E., S. L. Loeb, R. P. Axler, R. G. Carlton and C. R. Goldman. 1985. Transformations of nitrogen following an epilimnetic fertilization in Castle Lake, California. 1. Epilithic periphyton responses. Arch. Hydrobiologia. 102:425-433.

Zehr, J. P., R. P. Axler and C. R. Goldman. 1985. Heterotrophic mineralization of amino-acid nitrogen in subalpine Castle Lake, California. Marine Chem. 16:343-350.

Priscu, J. C., R. P. Axler and C. R. Goldman. 1985. Nitrogen metabolism of the shallow and deep-water phytoplankton in a subalpine lake. Oikos 45:137-147.

Sheehan, P. J., R. P. Axler and R. C. Newhook. 1986. Evaluation of simple generic aquatic ecosystem tests to screen the ecological impacts of pesticides. In: Community Toxicity Testing. ASTM STP, American Society of Testing and Materials, Philadelphia, Pennsylvania.

Axler, R. P. and J. E. Reuter. 1987. A simple procedure for estimating the N-15 content of dissolved organic matter (DON-15) in N-cycling studies. Canada. J. Fish. Aquat. Sci. 44:130-133.

Reuter, J. E. and R. P. Axler. In press. Physiological characteristics of inorganic nitrogen uptake by spatially separate algal communities in an N-deficient lake. Freshwater Biology.

Reuter, J. E. and R. P. Axler. In press. A comparison of methodologies used to measure nutrient uptake by periphyton. Verh. Internat. Verein. Limnol. 23.

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Sheehan, P. J., R. P. Axler and R. W. Newhook. In review. An experimental evaluation of a simple laboratory community toxicity test. Water Research.

Axler, R. P. and J. E. Reuter. In preparation. The importance of periphyton as a sink for nitrate in a subalpine lake: Mesocosm N-15 Pathways.

Axler, R., J. Reuter, J. Priscu, S. Loeb, R. Carlton, J. Zehr, J. Lane and C. Goldman. In preparation. Transformations of nitrogen following epilimnetic N-fertilization in Castle Lake, California.

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ABSTRACTS AND PRESENTATONS

Axler, R. P., L. Tager and M. Toll. 1969. Point contact tunneling phenomena in Nb (Nb-75 Zr-25). Yale Scientific. Proc. ECSC Meetings, Yale University, New Haven, Connecticut, April 1969.

Axler, R. P., R. M. Gersberg and C. R. Goldman. 1978. The importance of regenerated ammonium for epilimetic phytoplankton productivity. Presented at 41st Amer. Soc. Limnol. Oceanogr. Meetings, Victoria, British Columbia.

Axler, R. P., R. M. Gersberg and C. R. Goldman. 1979. The effect of molybdenum on inorganic carbon and nitrate uptake in Castle Lake, California. Presented at 42nd Amer. Soc. Limnol. Oceanogr. Meetings, Stonybrook, New York.

Axler, R. P., R. M. Gersberg and C. R. Goldman. 1980. Inorganic nitrogen uptake in a subalpine lake (Abstract). 43rd Amer. Soc. Limnol. Oceanogr. Meetings, Knoxville, Tennessee.

Axler, R. P., and C. R. Goldman. 1980. Isotope tracer methods for investigations of nitrogen deficiency in Castle Lake, California. Proc. FAO/IAEA Symposium, Burnaby, British Columbia, May 1980.

Axler, R. P., and R. M. Gersberg. 1980. Vertical patterns of inorganic nitrogen and carbon uptake in a subalpine lake. 21st Congress of the International Association of Limnology (SIL), Kyoto, Japan.

Axler, R. P., C. R. Goldman, J. E. Reuter, S. L. Loeb, J. C. Priscu and R. G. Carlton. 1982. Comparative studies of the nitrogen metabolism of phytoplankton and periphyton in oligotrophic lakes. Combined United Nations Food and Agriculture Organization/International Atomic Energy Agency Symposium on the fate of Agrochemical Residues in Food and the Environment, Rome, Italy.

Axler, R. P., J. Priscu, S. Loeb, R. Carlton, J. Zehr and C. Goldman. 1983. Transformations of nitrogen following N-fertilization in Castle Lake, California: Nitrate and ammonium depletion pathways. 22nd Congress of the International Association of Limnology (SIL), Lyons, France.

Axler, R., J. Reuter, D. Slotton and C. Goldman. 1987. Heavy metal distribution in a new reservoir downstream from an abandoned mercury mine. 23rd Congress of the International Association of Limnology (SIL), Hamilton, New Zealand.

REPORTS

Gersberg, R., R. Axler, S. Hackley and C. Goldman. 1980. Mesocosm eutrophication studies in Las Vegas Bay, Nevada. Las Vegas Valley Water Quality Standards Study (U.S. Environmental Protection Agency and Brown and Caldwell Consulting Engineers). 75 p.

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Axler, R., J. Reuter and C. Goldman. 1982. Lake Berryessa and Putah Creek: Baseline Water Quality Monitoring Study (Solano Irrigation District, California and Tudor Engineering Co. funding for an environmental impact assessment of Monticello hydroelectric power plant). 33 p.

Goldman, C., R. Axler and J. Reuter. 1982. Historical data synthesis and conceptual modeling of aquatic and terrestial ecosystems in the Tahoe Basin. Lake Tahoe Environmental Thresholds Study (Tahoe Regional Planning Agency and Brown and Caldwell Consulting Engineers-EPA funded). 230 p.

Goldman, C., S. Hackley, P. Arneson and R. Axler. 1982. Effects of highway de-icing agents on aquatic microbal commuities in the Tahoe Basin. (California Department of Transportation). 56 p.

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Axler, R., J. Reuter and C. Goldman. 1983. Evaluation of water quality in Fallen Leaf Lake, California (for Homeowner's Association). 27 p.

Axler, R. 1984. Establishment of ecotoxicity testing protocols for aquatic microcosms. (National Research Council of Canada-Ecotoxicology Group and Department of the Environment-Toxic Chemicals Program Contract File 03ST. 31048-3-3421). 22 p.

Axler, R. 1984. Evaluation of proposed Microcosm Toxicity Test Protocols. (National Research Council of Canada-Ecotoxicology Group and Department of the Environment-Toxic Chemicals Program, Contract File 24ST. 31048-4-2854). 12 p.

Reuter, J., R. Axler, S. Hackley and C. Goldman. 1985. The potential effect of parking lot snow disposal on Squaw Creek, California water quality. (Squaw Valley, USA Ski Corporation). 34 p.

Axler, R., J. Reuter and C. Goldman. 1985. Monticello Power Project: Lake Berryessa/Putah Creek Monitoring Program, 1983-1984. (Solano Irrigation District, California and Tudor Engineering Company). 10 p.

Axler, R., J. Reuter, D. Slotton and C. Goldman. 1986. Water Quality Monitoring Program for Davis Creek Reservoir, California: Summary and evaluation of data from the first year following impoundment. Institute of Ecology, University of California, Davis, 98 p.

Axler, R., J. Reuter and C. Goldman. 1986. Evaluation of McLaughlin Gold Mine Project-Environmental Monitoring Program for Davis Creek Watershed Surface Waters, 1985. Ecological Research Associates, Davis, CA. Tech. Rep. to Yolo County, California, March 1986, 96 p.

Axler, R., L. Paulson and D. Baepler. 1987. Preliminary Nutrient Enhancement Studies in Lake Mead, Nevada-Arizona. Final report submitted to U.S. Bureau of Reclamation, Boulder City, Nevada.

PETER DAVID VAUX

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EDUCATION

Ph D (Ecology), 1985. University of California, Davis, U.S.A.
B.Sc (honors) (Zoology), 1974. University of London, England.

PROFESSIONAL EXPERIENCE

Assistant Director: (Division of Limnological Research, Environmental Research Center, University of Nevada, Las Vegas, NV). Responsible for coordination and development of research programs on Colorado river system reservoirs. Projects include: water quality monitoring, fisheries enhancement using large-scale lake fertilization; benthos evaluation; crayfish population manipulations; experimental re-vegetation of littoral and drawdown regions; assessment of zooplankton community structure and production for evaluation of proposed forage fish introduction. Currently developing cooperative agreement between UNLV and Environmental Studies Division of Honduran National Power Company (E.N.E.E.) to promote research into environmental aspects of water resources development projects in Honduras (November 1987 to date).

Consultant Limnologist: (Land-Tech Consultants, Inc., Ridgefield, CT.) Responsible for development of company's aquatic resources consulting sector. Duties include supervision of water quality monitoring programs, lake evaluations and algal bioassay studies; data base analyses, development of restoration and management plans for series of Connecticut lakes and ponds; contribution to environmental impact assessment of river diversion project. (January 1987 to date).

Visiting Research Scientist: (Environmental Research Center, University of Nevada, Las Vegas, NV). Team member in large-scale experimental fertilization of Lake Mead for sports fishery enhancement. Involved in evaluating fertilization impacts on water quality, primary production, zooplankton nutritional status and population dynamics, and pelagic fish abundance. Carried out initial evaluation on possible use of otolith microstructure for determining growth rates of larval threadfin shad (May-July 1987)

Consultant Ecologist: (Empresa Nacional de Energía Eléctrica, Honduras). Advised Honduran power authority on environmental components of 300 MW El Cajón hydroelectric project. Aspects addressed include assessment and analysis of post-impoundment limnological data base, development of research program for reservoir and watershed management, and investigation of problem of H_2S contamination in dam power house. (1986 to date, includes total of 4 months of site visits)

Visiting Scholar: (King's College, University of London, England). Worked on initial planning phase of a reservoir environmental assessment and management handbook that is oriented towards developing countries of the tropics. (1986)

Graduate Student Researcher (University of California, Davis, CA) Responsible for data analysis and final report preparation for environmental impact study of El Cajon hydroelectric project (2 volumes river water quality/lake limnology and fisheries) Preparation of doctoral thesis (1983-85)

Research Scientist (Lake Titicaca, Peru/Bolivia) Member of 3-person team from Universities of California and Utah, carrying out base-line study of the Titicaca pelagic fishery Research included investigations of community structure, trophic ecology and otolith microstructure of native cyprinodonts (1984)

Research Scientist (La Selva Biological Reserve, Costa Rica) Member of 3-person team funded by Organization for Tropical Studies and the Noyes Foundation, studying periphyton nutrient limitation, water quality and feeding ecology of herbivorous fish in a rainforest stream (1984)

Resident Director, El Cajón Hydroelectric Project, Limnology and Fisheries Program, Honduras (Ecological Research Associates, Davis, CA) Responsible for development and management of limnological and ecological research program, operation of field laboratory, and training of Honduran scientists. Research included water quality monitoring in 3 river systems; a 2-lake comparative study of nutrient chemistry, primary production and zooplankton population dynamics; investigations of trophic and reproductive ecology, and population structure/dynamics of riverine and lacustrine fish species. (1980-83)

Research Assistant: (University of California, Davis, CA). Carried out research on zooplankton population dynamics and fish-zooplankton interactions at Lake Tahoe, California/Nevada. (1978-80)

Resident Ecologist and Field Coordinator (Nigeria) (Ecological Research Associates Davis, CA; Motor Columbus Consulting Engineers, Baden, Switzerland) Responsible for field research for environmental impact studies on Lokoja, Makurdi and Ikom hydroelectric projects, Nigeria. Coordinated field arrangements for Lokoja engineering/environmental feasibility study (1977-78)

Fisheries Officer. (Kwara State Government Ministry of Agriculture and Natural Resources, Nigeria) Managed fisheries development operations along a 500-mile stretch of the Niger and Benue rivers in Kwara State. Activities included operation of data collection program, establishment and management of fisheries cooperatives, construction of small floodplain impoundments, pond and cage aquaculture, and fisheries extension services (1974-77).

TEACHING EXPERIENCE

Teaching Assistant, limnology course, University of California, Davis (1980)

Instructor, limnology field class, Universidad Nacional Autónoma de Honduras (1981)

Thesis research advisor for Honduran university students. (1980-83)

Visiting lecturer for various ecology/limnology classes and seminars, at the University of California, Davis; University of London; National University of Honduras, and the Honduran School of Forestry Science (1979 to date)

Organizer of national seminar on environmental aspects of El Cajón hydroelectric project, Tegucigalpa, Honduras (1982)

PUBLICATIONS

Vaux, P.D., E. Vargas, A. Diaz and A. Flores, in press. The El Cajon reservoir: developing management strategies for a tropical impoundment. Lake and Reservoir Management.

Vargas, E. and P.D. Vaux, in press. Limnological and ecological considerations for hydropower development in Honduras. Lake and Reservoir Management.

Axler, R., L. Paulson, P.D. Vaux, P. Sollberger and D. Baepler, in press. Fish aid - the Lake Mead fertilization project. Lake and Reservoir Management.

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(Manuscripts Submitted for Publication or In Preparation)

Vaux, P.D and C.R. Goldman: Seasonality of water quality and nutrient transport in upland rivers of Honduras, Central America.

Goldman, C.R. and P.D. Vaux: The El Cajón project and its contribution to ecology in Honduras.

Vaux, P.D., E. Vargas, A. Diaz and A. Flores: The limnology of the newly impounded El Cajón reservoir in Honduras, Central America.

Vaux, P.D., C. Knud-Hansen and C.R. Goldman: An analysis of temporal variation in the nutrient chemistry and primary production of two Central American lakes.

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RESEARCH REPORTS

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Vaux. P D and C R Goldman. 1985 El Cajón Hydroelectric Project. Limnology and Fisheries Program. Final Report. Volume 2 Fisheries Ecological Research Associates. Davis CA. Motor Columbus Consulting Engineers. Baden. Switzerland 286pp

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Vaux. P.D., E Vargas and C.R Goldman 1982 Report on the infestation of *Eichhornia crassipes* in L de Yojoa. Honduras E.N.E.E., Honduras 20pp (In Spanish)

Vaux. P.D., 1979. Water quality. Fisheries *In* C.R Goldman. Makurdi Hydroelectric Project Environmental Impact Report Ecological Research Associates. Davis. CA. Motor Columbus Consulting Engineers. Baden. Switzerland

Vaux. P.D., 1978. Fisheries *In* C.R Goldman. Lokoja Hydroelectric Project Environmental Impact Report Ecological Research Associates. Davis. CA; Motor Columbus Consulting Engineers. Baden. Switzerland.

HONORS/AWARDS

Distinguished Scholar Award (graduate student). 1979-80. University of California Davis.

PROFESSIONAL AFFILIATIONS

American Association for the Advancement of Science
American Society of Limnology and Oceanography
North American Lake Management Society
Sigma Xi
British Ecological Society
Nigerian Field Society

LANGUAGES

Spanish (fluent); French (spoken and read). Portuguese (read)

VIII. FACILITIES OF THE ENVIRONMENTAL RESEARCH CENTER, UNIVERSITY OF NEVADA, LAS VEGAS

ERC

Environmental Research Center
University of Nevada, Las Vegas
Las Vegas, Nevada 89154
(702) 739-3382

ENVIRONMENTAL RESEARCH CENTER

University of Nevada, Las Vegas

A. Overview

The Environmental Research Center is a research entity of the University of Nevada, Las Vegas located on the campus of the University in the Museum of Natural History with additional offices and facilities in Nashville, Tennessee, and in Reno and Las Vegas, Nevada. Research is performed under contracts, grants, and cooperative agreements with various federal, state, and local governmental agencies and commercial, industrial, and private clients. The Center's programs require the focusing of extensive experience, expertise, and resources in the conduct of environmental monitoring studies, human exposure assessments, cultural resource inventories, geothermal potential assessments, and monitoring methods and systems development, in providing technical support, and in the operating of a national referee quality assurance laboratory. In addition to its own staff, the Center uses the services of the professorial staff of the University and outside consultants. It also engages in cooperative activities with research organizations at various sites about the country.

The Environmental Research Center is capable of conducting research in the following areas:

Environmental Monitoring and Impact Assessment

- Multimedia
  (Air, Groundwater, Soil, Vegetation, Surface Water, Terrestrial and Aquatic Food Chains)
- Radiation
- Noise
- Visibility
- Toxics and Hazardous Waste
- Integrated Exposure and Risk Assessments
  (Human Health and the Environment)
- Cultural Resource Inventories and Site Mitigation
- Transport, Fate and Effects Studies
- Terrestrial and Aquatic Community Structure
- Statistical (including Geostatistical) Design/Evaluation of Monitoring Programs and Sampling Networks
- Model Development and Validation
- Optimal Monitoring System Design to Achieve Defined Objectives
- Limnological and Fisheries Studies

Methods and Technology Development

- Remote Sensing
  - Geophysical Methods
  - Airborne and Ground-based,
    Passive and Laser Active Systems
- Analytical Methods
- Environmental Monitoring

Geostatistical Methods

Toxicity Testing and Development of Exposure-Dose-Response Relationships

Quality Assurance

Referee Analyses

SRM and Performance Evaluation Sample Preparation

Sample Bank Operation

Performance and Systems Audits

Technology and Guidelines Development

Quality Assurance Plan Design

Technical Support

Statistical Design of Monitoring Programs

Quality Assurance

Technology Transfer (including Training Seminars)

Models

Verification/Validation

Guidelines Development for Field Testing

Model Selection for Specific Applications

Optimization

Energy

Geothermal Potential Assessments

Surface and Fluid Geochemistry

Solar Potential Assessments

Science Policy

Public Policy Studies

Scientific and Technological Capability Assessments

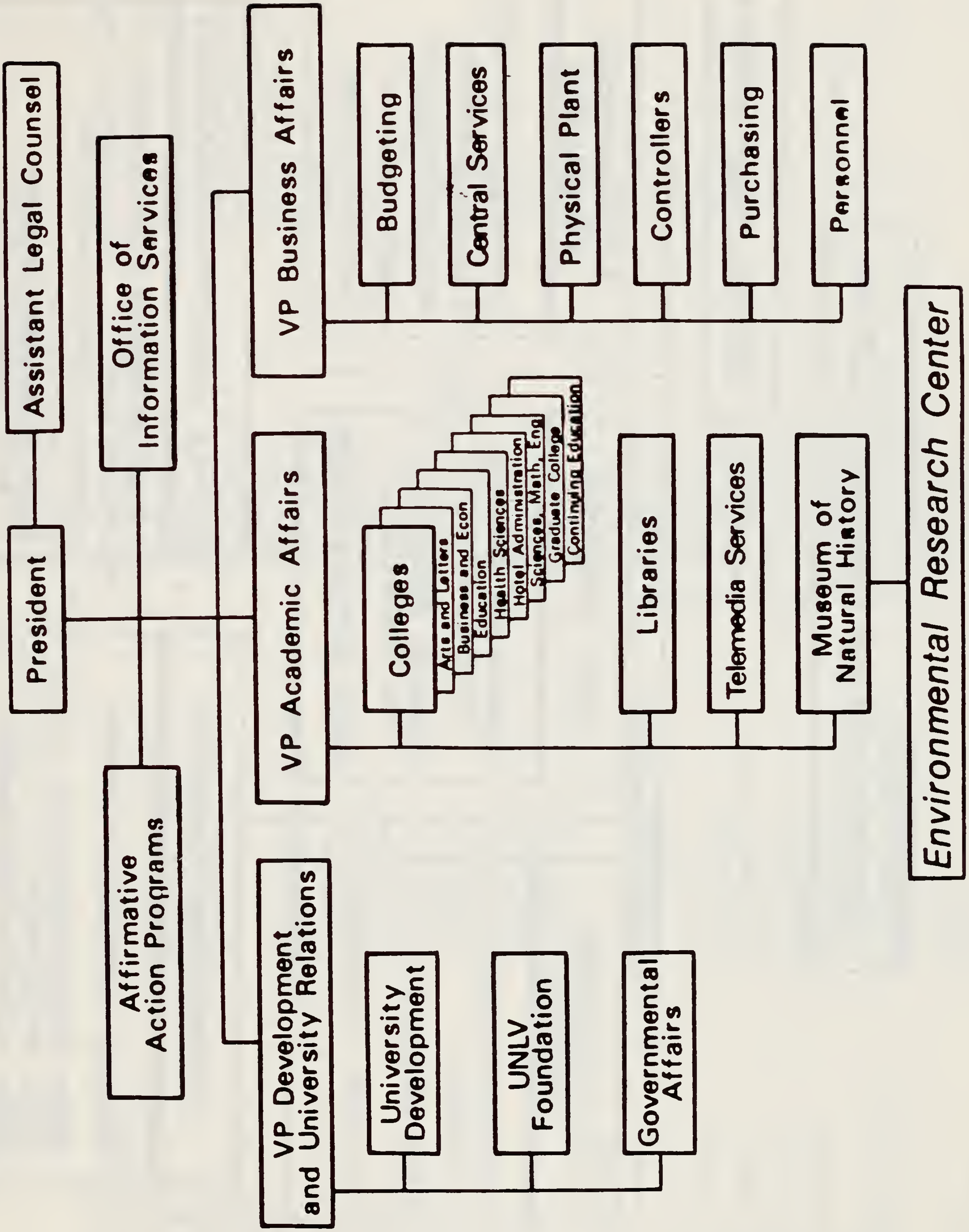
Assessment of Policy Alternatives and Potential Impacts

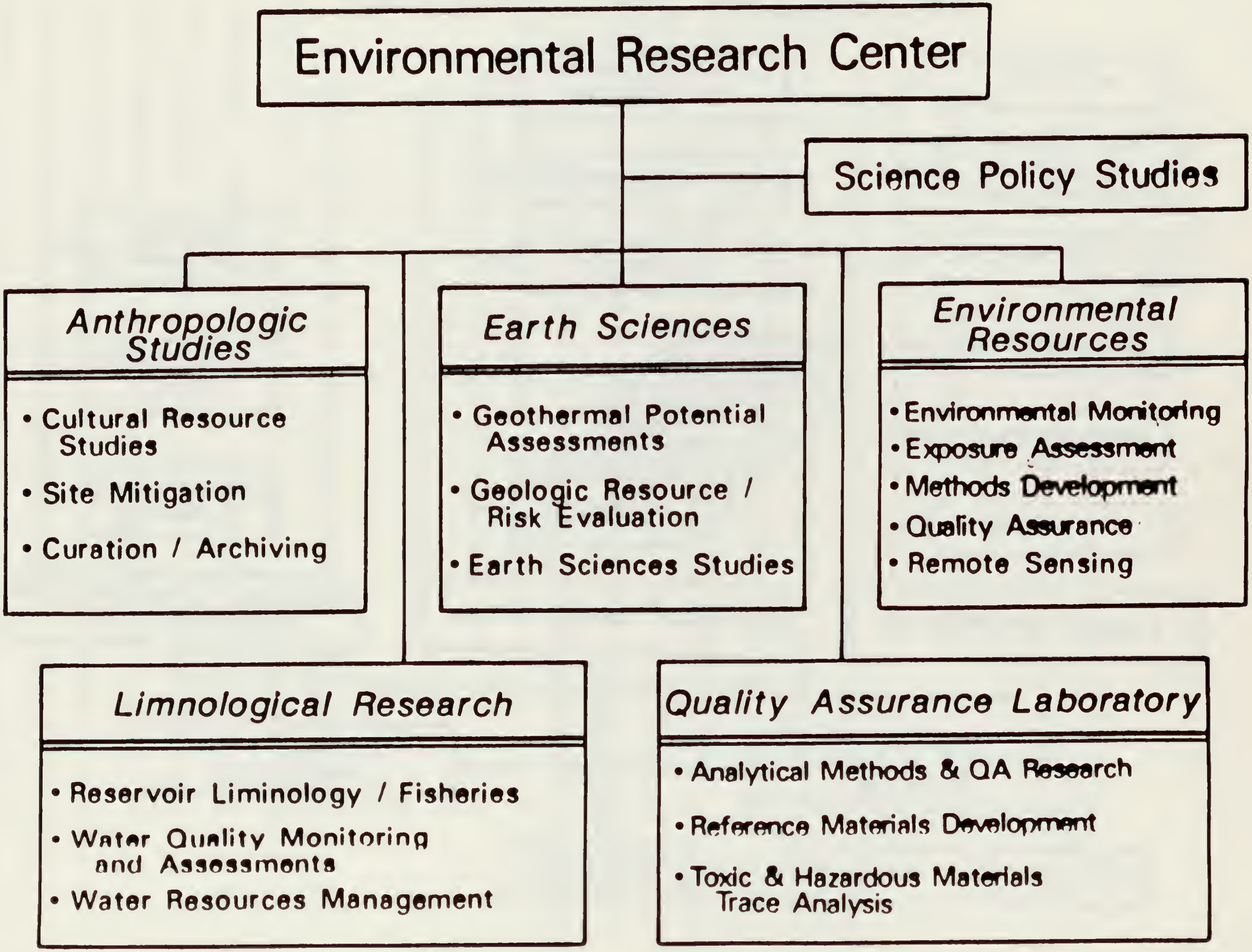
B. Organization and Staffing

The Environmental Research Center was organized within the University of Nevada's Museum of Natural History in 1981 although three of its Divisions (Division of Anthropological Studies, Limnological Research Center, and Division of Earth Sciences) have considerably longer histories. The University's general structure and the Center's organization and current staffing are shown on the following three charts. Other scientists are added as necessary to meet program requirements.

C. Facilities and Specialized Equipment

The Environmental Research Center has adequate office, laboratory and support facilities in which to conduct its programs. Specialized facilities include over 6500 square feet of analytical chemistry laboratory with a bio-containment lab, a wet chemistry lab and four instrumentation labs. In addition, the University of Nevada, Las Vegas, has extensive computer facilities (CDC Cyber 730, 172/8 and 73, 2 Harris H-800s and a DEC PDP-11/34) with a complete set of support peripherals and a


President
Assistant Legal Counsel
Office of Information Services
Affirmative Action Programs
VP Development and University Relations
University Development
UNLV Foundation
Governmental Affairs
VP Academic Affairs
Colleges
Arts and Letters
Business and Econ
Education
Health Sciences
Hotel Administration
Sciences, Math, Eng
Graduate College
Continuing Education
Libraries
Telemedia Services
Museum of Natural History
Environmental Research Center
VP Business Affairs
Budgeting
Central Services
Physical Plant
Controllers
Purchasing
Personnel


Environmental Research Center
Science Policy Studies
Anthropologic Studies
• Cultural Resource Studies
• Site Mitigation
• Curation / Archiving
Earth Sciences
• Geothermal Potential Assessments
• Geologic Resource / Risk Evaluation
• Earth Sciences Studies
Environmental Resources
• Environmental Monitoring
• Exposure Assessment
• Methods Development
• Quality Assurance
• Remote Sensing
Limnological Research
• Reservoir Liminology / Fisheries
• Water Quality Monitoring and Assessments
• Water Resources Management
Quality Assurance Laboratory
• Analytical Methods & QA Research
• Reference Materials Development
• Toxic & Hazardous Materials Trace Analysis

ENVIRONMENTAL RESEARCH CENTER

David N. McNelis; Ph.D., Director
Delbert S. Barth; Ph.D., Senior Scientist
Lynn Fenstermaker; M.S., Technical Assistant
Amy Smiecinski; M.S., Q.A. Specialist
Gina Strebel, Management Assistant
Carol L. Forsythe, Management Assistant
Leslie E. Gorr, Word Processing Operator
Vacant, Administrative Aid
Kimberly Kershaw, Student Aid

Limnological Research

L. Paulson; Ph.D., Director
  Limnologist
P. Vaux; Ph.D.
  Limnologist
R. Axler; Ph.D.
  Limnologist/Ecologist
W. Pratt; Ph.D.
  Taxonomist
J. Haley; M.S.
  Plant Ecologist
Vacant; M.S.
  Biologist
Vacant; M.S.
  Plant Ecologist
S. Peck; M.S.
  Aquatic Ecologist Technician
P. Sollberger; B.A.
  Limnological Field Technician
M. Schmeltzer; M.S.
  Laboratory and Field Technician
Vacant; B.S.
  Laboratory Technician
L. Cody
  Laboratory Research Assistant
K. Coxi
  Computer Programmer
M. Herrera
  Computer Programmer
S. Leavitt
  Research Assistant
D. LeMaster
  Laboratory Technician
S. Paulson
  Analytical Chemist
G. Rappaport
  Laboratory Assistant
M. Salas
  Laboratory Assistant
L. Shepard
  Mechanic
S. Stonehocker
  Laboratory Field Assistant

* Associates
** Leave of Absence

Earth Sciences

D. Trexler; M.S., Director
  Geologist
T. Flynn; M.S.
  Geologist
S. Wehrkamp
  Management Assistant

Anthropological Studies

K. Rafferty; Ph.D., Director
  Archaeologist
R. Brooks; Ph.D.
  Sr. Archaeologist
L. Blair; M.S.
  Archaeologist
P. Calos; B.A.
  Archaeologist
G. Tullis; M.A.
  Archaeologist
S. Edwards; B.A.
  Archaeologist
L. Hendrickx; M.A.
  Archaeologist

Environmental Resources Associates

P. Amy; Ph.D.*
  Microbiologist
D. Devitt; Ph.D.*
  Environmental Scientist
W. Jury; Ph.D.*
  Soil Physicist
B. Mason; Ph.D.*
  Soil Scientist
F. Schwille; Ph.D.*
  Hydrogeologist

Environmental Resources Student Technicians

S. Baker
M. Buttner
H. Reed
B. Green

Environmental Resources

R. Evans; Ph.D., Director**
  Environmental Engineer
D. Diebel; Ph.D.
  Physicist
C. Chen; Ph.D.
  Biostatistician
P. Kuroda; Ph.D.
  Radiochemist
C. Palmer; Ph.D.
  Soil Scientist
M. Pandian; Ph.D.
  Chemical Engineer
S. Paulsen; Ph.D.
  Limnologist
T. Starks; Ph.D.
  Sr. Statistician
K. Stetzenbach; Ph.D.
  Environmental Scientist
L. Stetzenbach; Ph.D.
  Microbiologist
D. Weber; Ph.D.
  Geophysicist
R. Zimmerman; M.S.
  Physicist
C. Fitzsimmons; M.S.
  Environmental Scientist
H. Hiatt; M.S.
  Biologist
M. McGown; M.S.
  Meteorologist
C. Morgan; M.S.
  Hydrogeologist
R. Viswanathan; M.S.
  Meteorologist
S. Rohde; B.A.
  Cartographer
K. Lauckner; B.S.
  Quality Assurance Specialist
K. Pickering; B.S.
  Environmental Engineer
D. Turner; B.S.
  Electronics Engineer
R. Reno; B.S.E.
  Chemical Engineer
Vacant; Ph.D.
  Toxicologist
Vacant; B.S./M.S.
  Chemist (Immunoassay)

Quality Assurance Laboratory

J. Campana; Ph.D., Director
  Chemist
V. Hodge; Ph.D.
  Inorganic Group Leader
M. Saleh; Ph.D.
  Organic Group Leader
C. Jones; B.S.
  Research Chemist
K. Zarrabi; Ph.D.
  Research Chemist
K. Bonaparte; B.S.
  Research Associate
H. Hendler; B.S.
  Chemist
Vacant; B.S./M.S.
  Research Associate
S. Ward; B.S.
  Chemist
V. Kelliher; A.A.
  Chemist
W. Thompson
  Chemist
J. Yang; Ph.D.
  Postdoctoral Fellow
T. Hsu; Ph.D.
  Postdoctoral Fellow
D. Darby
  Chemist Trainee
G. Smith
  Chemist Trainee
A. Covert
  Administrative Assistant
V. Angeles
  Administrative Aid

Science Policy Studies

G. Schweitzer; M.S., Director*

12/87

full range of craft shops (including electronic and mechanical) available to the Environmental Research Center for its programs.

The Environmental Research Center has the specialized equipment listed in the appendix available for use in its research efforts.

DIVISION OF ANTHROPOLOGICAL STUDIES

The Division of Anthropological Studies, previously known as the Nevada Archaeological Survey, Southern Division and the Archaeological Research Center, is the principal cultural resource management organization in southern Nevada. The Division also provides services in a multi-state area, including California, Arizona, and Utah. The group, consisting primarily of archaeologists, includes ethnobiologists as well.

Funding is principally from one of three sources: contracts entered into with private firms such as housing developers, construction firms, and other private entities attempting to comply with federal laws and regulations; contracts awarded by Federal agencies such as the Bureau of Land Management, the Bureau of Reclamation or the U.S. Fish and Wildlife Service; and grants awarded by the Nevada State Division of Archaeology and Historic Preservation for surveys and excavations designed to provide cultural resource management data. The division has completed a number of regionally oriented surveys, site specific research excavations, mitigation excavations and numerous smaller cultural resource management surveys in Nevada, California, Utah and Arizona. Examples of such projects conducted for Federal Agencies include several Class II surveys for the Air Force on the Nellis Bombing and Gunnery Range, cultural resource over-views and surveys for the National Park Service in the Lake Mead National Recreation Area, Class II surveys for the Bureau of

Land Management in the California Desert District, the Las Vegas District and the Ely District, and test excavations for the Las Vegas District at potential National Register Quality sites. Major surveys, including several in the Las Vegas Valley and in eastern Clark County, have been conducted for the Nevada State Division of Archaeology and Historic Preservation over the last few years. An extensive list of survey and mitigation projects for private firms have also been accomplished.

Cultural resource management is not the sole goal of the Division of Anthropological Studies. Its scientists are encouraged to conduct research into the prehistory of southern Nevada, and other study areas, and to publish the results of this research. Their articles have appeared in the Nevada BLM Cultural Resources Technical Report series, the Nevada Archaeologist, and the Nevada Historical Society Quarterly. Several monographs have also been published and papers have been presented at professional meetings including those of the Society for American Archaeology, the Arizona-Nevada Academy of Sciences and the Great Basin Anthropological Conference.

In total, the Division of Anthropological Studies concerns itself with the entire field of archaeological endeavor: cultural resource management, research into prehistory and theoretical issues, and dissemination of data to the professional and lay community. It also provides a unique opportunity for university students to acquire practical experience in their chosen field.

DIVISION OF EARTH SCIENCES

The Division of Earth Sciences, located in Reno, Nevada, is the principal non-state supported geological research group in the state. Professional staff members have advanced training and vast experience in all phases of geoscientific research and management with expertise in geothermal exploration, drilling management, geologic hazards and seismic risk evaluation, remote sensing, groundwater hydrology, mineral and energy resources inventory, geochemical surveys, and fluid waste disposal.

Funding for research activities is supported by the federal government and private industry. Agencies within the federal government using the Division's expertise are the Department of Energy, and Geothermal Technologies Division; Department of Defense, Naval Weapons Center, China Lake; and the Department of Interior, Geological Survey. These activities have included regional assessments of geothermal resources in Nevada and California, as well as site specific investigations throughout Nevada including Caliente, Hawthorne, Reno (Moana), Carlin, Big Smoky Valley, Pumpernickel Valley, Paradise Valley, and Carson-Eagle Valleys.

Techniques employed included geologic mapping, low-sun-angle photography, soil mercury analysis, shallow temperature measurements, geochemistry, geophysics, and temperature gradient drilling. Each technique provides information on the geothermal resource. Geologic mapping, analysis of low-sun-angle photography and geophysical techniques provide data on the structural controls delimiting the resource. Soil mercury analysis provides information on near surface conduits of mercury vapor migration while geochemical and isotopic analysis indicate recharge, maximum reservoir temperatures, and depth of fluid migration. Direct temperature measurements at a depth of two meters defines the near surface manifestation of buried geothermal resources and, coupled with temperature gradient drilling, provide data on the depth to the resource.

The Division, under the auspices of the U.S. Department of Energy in conjunction with NOAA and the U.S. Geological Survey, has prepared a map of the Geothermal Resources of Nevada. The map, coupled with a vast computer-based data system, provides easy access to information on geothermal resources.

In cooperation with the American Museum of Natural History, Division staff performed geomorphological and stratigraphic analysis of the Gatecliff archaeological excavation in central Nevada.

Division of Earth Sciences staff have performed non-funded basic geoscientific research in areas significant to the semi-arid western U.S. in cooperation with scientists from Purdue University. The results of this effort were summarized in a paper presented at the Eighth Annual Geomorphology Symposium in Binghampton, New York, on "The Equilibrium and Activation of Aeolian Processes in the Great Basin."

Results of the Division's research activities are published in journals, topical reports, and non-technical publications (such as Nevada Magazine). Presentations to civic groups, county and state administrators, as well as providing information to the general public, are major avenues of technology transfer.

DIVISION OF ENVIRONMENTAL RESOURCES

The Division of Environmental Resources has perhaps the broadest charter, both with respect to scientific disciplines and geography, to conduct environmentally-related measurement, monitoring, and assessment programs.

Assessment programs have included such diverse activities as the development of an exposure-assessment guidelines document for the EPA, the preparation of a chapter on exposure assessment for a National Science Foundation book on risk assessment prepared for the Office of Management and Budget, the characterization of EPA's Exposure Methods Testing Site (Chattanooga, Tennessee), participation with the World Health Organization and several countries around the world in conducting Human Exposure assessments for organochlorine pesticides and for cadmium and lead, the publication of an assessment of the science and technology capacity of Nigeria for the World Bank, and the conduct of a number of multimedia, impact assessments for state and engineering consultant clients.

Measurement and monitoring programs extend from the field to the laboratory and include measurements, methods, and instruments development, QA systems and performance audits, and methods and guidelines development. Quality Assurance Users Guides for Soil and for Sediment Sampling have been completed for the Environmental Protection Agency, and one for groundwater sampling is planned.

The Division also provides, as a major program area, technical support to federal, state, and local governmental agencies and to industrial and private clients. Expertise in experimental design, multimedia sampling, measurement and monitoring methods, quality assurance policies and practices, sample handling procedures, laboratory analytical techniques, statistical analyses (classical and geostatistical), and automated data-processing practices and systems is provided by Center personnel as required.

Some examples of activities in a less conventional monitoring method, i.e., remote sensing, include the development of a new generation laser fluorosensor for making measurements of selected surface water parameters and a computer-driven plume-opacity lidar system, evaluation and interpretation of lidar and visibility monitoring systems data, assessment of the impact of land use on a section of the intercoastal waterway in Florida (using interpreted aerial imagery), and the provision of training in geophysical methods including their application in hazardous waste site investigations.

Finally, Division scientists, along with those from other Center elements, participate in the development and presentation of academic programs and in the sponsorship of graduate research.

LIMNOLOGICAL RESEARCH CENTER

The Lake Mead Limnological Research Center (LRC) was established at the University of Nevada, Las Vegas by the Nevada State Legislature in July 1979. The principal purpose of this center is to conduct applied research in areas of limnology, water quality, aquatic ecology, fisheries, and water resources management in Lake Mead and other reservoirs in the southwestern United States.

The LRC has conducted limnological or related research for several local, state, and federal agencies including Clark County, the City of Las Vegas, Nevada Department of Wildlife, Nevada Division of Environmental Protection, Office of Water Research and Technology, Four Corners Regional Commission, U.S. Bureau of Reclamation, U.S. Environmental Protection Agency, and the U.S. Fish and Wildlife Service. The Center has also served as a subcontractor on water quality studies for large engineering firms (e.g., Brown and Caldwell and Culp/Wesner/Culp) and has provided technical assistance on reservoir management for large-scale residential developers (e.g., Pacific Malibu Corporation and Collins Brothers).

The LRC recently completed a series of environmental assessments for the Bureau of Reclamation on uprating of the Hoover Dam Powerplant. That research included detailed field and laboratory studies to define limnological conditions in Lake Mead and Lake Mohave, the downstream reservoir, under present and future operating conditions of Hoover Dam. The Hoover Dam assessments also included: 1) an evaluation of effects of dredging and high discharges on the ecology of the Colorado River below the dam; 2) a modeling study of the effects of temperature and water-level fluctuations from the dam on the fisheries in Lake Mohave and; 3) an analysis of the historical trophic status of Lake Mead, based on a detailed sampling of the chemical and biological structure of bottom sediments.

The LRC has also conducted several other investigations in Lake Mead and other reservoirs. Those include: a two-year limnological study of Lake Powell, Lake Mead, Lake Mohave, and Lake Havasu to determine serial effects of dam operations on water quality in the Colorado River; an evaluation of how large dams could be used to better manage nutrients, productivity, salinity, and evaporation in multi-reservoir systems; a water quality study to establish standards on effluents discharged into Lake Mead; an evaluation of relationships among nutrients, plankton, and striped bass in Lake Mead; and a study of the reproductive status of native fishes in Lake Mohave.

LRC staff and students have published numerous technical reports, theses, and papers on their research findings. The Lake Mead Limnological Technical Report Series is widely disseminated to universities and governmental agencies. Several LRC papers recently were published in a book entitled Aquatic Resources Management of the Colorado River Ecosystem. Research findings also have been presented at scientific societies such as the Ecological Society of America, American Society of Limnology and Oceanography, American Fisheries Society, Arizona-Nevada Academy of Sciences, Water Pollution Control Federation, and The Society of Wetlands Scientists.

The LRC interacts closely with several other research groups in the country including the Oak Ridge National Laboratory, the Tahoe Research Group at the University of California, Davis; and the Lake Texoma Biological Station at the University of Oklahoma.

The LRC has the equipment to outfit two limnological field research teams with trucks, research boats, and sampling equipment. The Center operates a certified analytical laboratory, and it is capable of conducting routine chemical and biological analyses of freshwater.

QUALITY ASSURANCE LABORATORY

The Quality Assurance Laboratory was established to support the Environmental Protection Agency's responsibilities under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA). Specifically, the Laboratory provides the EPA with an expanded technical capability to develop, evaluate, and implement quality assurance/quality control procedures which are critical to the integrity of the EPA Contract Laboratory Program and the analysis of samples from the environs of hazardous waste sites.

The laboratory is composed of four research sections--organic, inorganic, mass spectrometry, and methods development; and the facility has four instrument laboratories, a wet-chemistry/sample-preparation laboratory, and a regulated containment laboratory. The containment lab is used for handling hazardous materials, for example, during the preparation of dioxin reference materials and the chemical preparation of performance evaluation samples, other referee samples, and samples from waste sites for instrumental analysis.

The Quality Assurance Laboratory has a major responsibility for the evaluation of analytical protocols under consideration for implementation in the EPA's Contract Laboratory Program and for conducting analytical methods research. The goals of these efforts are improved protocols and methods and the solution of future or anticipated analytical problems associated with new classes of hazardous compounds and sampling methods.

The laboratory performs referee analyses on a variety of standards, standard materials, and performance evaluation and other test samples. The laboratory is also responsible for developing a variety of calibration solutions and reference materials and then for providing a bank of these new quality assurance materials; in addition, senior scientists participate in evaluations and audits of contract laboratories at various sites across the country.

Scientists within the laboratory are encouraged and supported to pursue fundamental research related to the laboratory's mission. The laboratory also supports academic research programs and training at the undergraduate and graduate level in chemistry.

SCIENCE POLICY STUDIES GROUP

The objectives of the Science Policy Studies Group are to improve understanding related to the interactions of policy and technology on matters of critical importance to Nevada and of national significance, and to broader educational opportunities at the University of Nevada, Las Vegas. The group was formed to provide an opportunity for scientists and students to develop the analytical skills and the substantive backgrounds that will allow them to lead rather than follow in formulating future policies that will be heavily driven by rapid technological developments. At the same time the Center, with its associates and affiliations within the university, the local community, and nationally, has outstanding multidisciplinary expertise which can provide an intellectual base for the development and conduct of research programs in the area of public policy.

APPENDIX

- High-Resolution Gas Chromatograph/high-resolution triple-sector (BEB) Mass Spectrometer (VG ZAB-3F)
- Chromatograph/Mass Spectrometer (Finnigan 4510)
- Gas Chromatograph (Tracor)
- Gas Chromatograph/Mass Spectrometer (Finnigan OWA-30B)
- Gas Chromatograph/High-Pressure Liquid Chromatograph (Varian Vista 54/6000)
- Atomic Absorption Spectrophotometer W/HGA Graphite Furnace (Perkin Elmer 5000)
- Atomic Absorption Spectrophotometer (Flame) (Perkin Elmer 5000)
- Atomic Absorption Spectrophotometer (Zeeman type) (Hitachi 170-70)
- Ion Chromatograph (HPLC with Biorad Conductivity detector)
- UV-Visible Spectrophotometer (Beckman DU 8)
- IR Spectrophotometer (Beckman 4250)
- Inductively-Coupled Argon Plasma Emission Spectrometer (Bausch & Lomb ARL 35000)
- Gas Chromatograph (Hewlett Packard 5880)
- Gel Permeation Chromatograph with Autosampler and Sample Collection System
- Autoanalyzers (2) (Technicon II)
- General Lab Instruments (Mettler Balances, Ovens, Stirrers, refrigerated centrifuge, etc.)

- Microprocessors
  IBM (PC,XT and AT), Perkin Elmer, Nova,
  PDP 11/23, Varian, Hewlett Packard
- Lanier Word Processing Units (Local Area Network)
- Multichannel Data Loggers
  (Monitor Labs 7200 and 9400)
- Graphite Crystal Monochronometer
- Radiation Diffraction Unit (Norelco)
- International Scientific Scanning-Electron
  Microscope
- X-ray Instrument (Siemans)
- Solid State Detector Controller (Laser Fluorosensor System)
- Hydrocarbon Analyzers (Beckman)
- Integrating Nephelometers (MRI)
- NO_x Instruments
- Zoom Transfer Scope (Bausch & Lomb)
- Light Table with Binocular Stereoscopic
  optics
- V-Blender, 5 kg capacity
- Soil Augers (Power and Hand)
- Down-hole (15001) Temperature Probes
- 40-2M Temperature Probes
- Water-Level Indicators
- Down-Hole Water Samplers
- Binocular Petrographic Microscope (Olympus)
- Water Quality Measurement System
  (Hydrolab 8000)

- Mobile Bioassay Laboratory/Trailer (2)
  each with Mount-Brungs Proportional Diluter
- Universal Microscope (Zeiss)
- LI-COR PAR Measurement System
- Digital-Integrating Sound Level Meter (Quest)
- 1 1/2 Ton Van (Ford)
- Two 25 foot Aluminum Jet Boats w/Trailer
- Water Quality Analyzer (2) (Hydrolab, Models
  4000 & 8000)
- Field & Laboratory Fluorometers (2) (Turner)
- Underwater Transmissometer (Marteck)
- Temperature-Conductivity Meter (Whitney)
- Field Recorder (Hewlett Packard)
- Carbon/Nitrogen Analyzer (Perkin Elmer)
- Liquid Scintillation Counter (Beckman)
- Spectrophotometer (Perkin Elmer Model 55)
- Spectrophotometer (Perkin Elmer Model 552)
- Gas Chromatograph (FID) (Carle)
- Balances (4)
- Echo Sounder (Furuno)
- Underwater Photometers (2) (Li-Cor)
- Turbidity Meter (Hack)
- Weathermaster Pyranometer (2)
- Underwater Video-tape Camera
- Underwater Scuba Gear
- Laboratory Incubators
- Quartz-Glass Distillation Apparatus

IX. APPENDICIES

Appendix 1. SELECT NEWSPAPER AND MAGAZINE ARTILCES ABOUT THE LAKE MEAD FERTILIZATION PROJECT

- "Fertilization: Bringing a Dying Lake Back to Life, Orange County Register, February 12, 1987.

- "Lake Mead Fertilization Planned" Las Vegas Review Journal, February 18, 1987.

- "Fertilization Project Set for Lake Mead", Las Vegas Sun, February 18, 1987.

- "Bass Fishermen Try a Unique Plan to Aid Lake Mead", Los Angeles Times, February 27, 1987.

- "New Life for a Dying Lake", Arizona Hunter and Angler, April 1987.

- "Lake Mead on the Mend", BassMaster Magazine, April 1987.

- "Fertilizer Smells Sweet to Lake Mead Fishermen", Fishing and Hunting News, April 2, 1987

- "Nutrient Plan Ok'd", Las Vegas Sun, April 18, 1987.

- "A Salute to the Many Volunteers - and a Very Special Man", Las Vegas Sun, April 26, 1987.

- "Mead Artificial Fertilization Project has Wide Support", Las Vegas Review Journal, May 7, 1987

- "Lake Mead Artificial Fertilizer Plans Approved, Las Vegas Review Journal, May 28, 1987.

- "More Than 1000 Volunteers Help in Lake Mead Fertilization Project", Las Vegas Sun, May 31, 1987.

- "Lake Lovers Return Something to Mead", Las Vegas Review Journal, May 31, 1987.

- "Non Fishing Boaters Helped with Project", Las Vegas Review Journal, June 4, 1987.

- "The Reviving of an Ailing Fishery", Los Angeles Times, June 10, 1987.

- "Lake Mead: The Reviving of an Ailing Fishery Begins", Reno Gazette-Journal, June 14, 1987.

- "Lake Mead Fertilization Project Tremedous Success", Las Vegas Review Journal, July 9, 1987.

- "Overton Arm Striper Action About as Hot as the Weather", Las Vegas Review Journal, August 6, 1987.

- "Beefing Up the Bass", Nevada Fins and Feathers, July/August, 1987.

- "The Las Vegas Tea Party", Fishing Facts, September 1987.

- "Lake Mead Fertilization Is Working So Far", The Press-Enterprise, September 4, 1987.

- "Overton Arm Producing Heavy Top Water Action", Las Vegas Review Journal, October 22, 1987.

- "Good Catches Still Being Taken Near Rogers Bay", Las Vegas Review Journal, November 12, 1987.

- "Echo Bay Hottest Fishing Locale", Las Vegas Review Journal, December 10, 1987.

Appendix 2.

FERTILIZATION PROJECT REGISTRATION PACKET
GROUND CREW, CAPTAINS, AND BOAT CREWS

Thank you for volunteering! There will be an important meeting on:

MAY 19, 1987
7:30 PM
HUMANITIES AUDITORIUM, ROOM 109
(the tallest building on campus)
UNLV, Maryland Parkway

Operations for the boats will be discussed but ground crew members are welcome to attend.

Please check the fishing columns in the sports sections of the local newspapers every Thursday for further updates.

****

This is your Fertilization Project Registration Packet. Enclosed in this packet are:

- GROUND CREW WORK SCHEDULES (we need help from boaters, too) and
  FERTILIZER JUG PICK-UP SCHEDULES (PERMANENTLY moored boats can pick-up jugs at Echo Bay on May 29 and May 30 or at Sunset Marine and Tackle as described in the schedule)
- BOAT IDENTIFICATION FORM (your boat number, your jug load, and your launch time are listed on this form)
- FERTILIZATION FLOTILLA DIAGRAM
- NDOW letter with matching fund information.

BRING THIS WHOLE PACKET TO ECHO BAY ON MAY 30!!!! You will need it to pick-up your tickets for the

- Free Barbeque
- Raffle Drawing
- And free entry into the Al Cieri Memorial Fishing Tournament

****

• IMPORTANT:

If your boat is permanently moored and you have not already been contacted by phone, please call 739-3381 and leave your name, boat size, and if you will be picking up your fertilizer from the barge at Echo Bay or from Sunset Marine and Tackle. We need this information as soon as possible.

GROUND CREW WORK SCHEDULE (Boaters Needed, Too!)
and
FERTILIZER PICK-UP SCHEDULE

Jug filling and jug loading operations will follow the schedule below. Jug filling will be much less strenuous than loading the jugs onto trailered and moored boats.

We hope that boat captains will make every effort to pick-up their fertilizer according the following schedule. We have arranged the schedules to prevent tie-ups on the last day. A limited amount of fertilizer will be available between 3AM and 7AM at Sunset Marine and Tackle on May 30. Some fertilizer jugs will be available for loading on May 30 along the Echo Bay Road for trailered boats coming in from out of town. Permanently moored boats will be loaded from barges in the Echo Bay Harbor. We strongly urge captains of moored boats to pick-up their fertilizer jugs on Friday afternoon, May 29 to avoid congestion at the barges early on Saturday morning.

You can call Don Sollberger at Sunset Marine and Tackle at 565-0696 or Larry Paulson at UNLV at 739-3381 for more information.

* * *

FERTILIZATION PROJECT - GROUND CREW JOBS

Date	Time	Location	Task
Friday - May 15	3PM-11PM	Sunset Marine	Fill jugs on ground
Saturday - May 16	8AM-8PM	"	"
Friday - May 22	3PM-11PM	"	"
Saturday - May 23	8AM-NOON	"	"
Wednesday - May 27	2PM-11PM	Echo Bay	Fill jugs on barges
Thursday - May 28	2PM-11PM	"	"
Wednesday - May 27	6PM-9PM	Sunset Marine	Load jugs onto trailered boats
Thursday - May 28	6PM-9PM	"	"
Friday - May 29	6PM-9PM	"	"
Saturday - May 30	3AM-7AM	"	"
Friday - May 29	2PM-9PM	Echo Bay	Load jugs onto Permanently moored boats
Saturday - May 30	5AM-8AM	"	"
Saturday - May 30	5AM-3PM	Echo Bay	Traffic Control
Saturday - May 30	3PM-9PM	"	Clean-up

* * *

FERTILIZER PICK-UP SCHEDULE
(Except permanently moored boats)

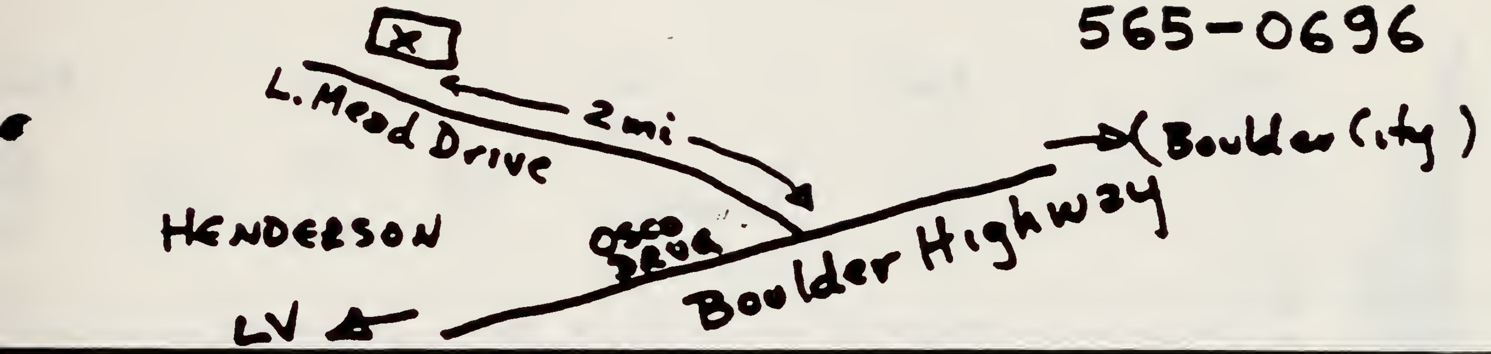
Boat Number	Date	Time	Location
1 - 180	Wednesday - May 27	6PM - 9PM	Sunset Marine
181 - 300	Thursday - May 28	6PM - 9PM	Sunset Marine
301 - 400	Friday - May 29	6PM - 9PM	Sunset Marine

• (Permanently moored boats can pick up fertilizer between 2PM and 9PM on May 29 and between 5AM and 8AM on May 30 at Echo Bay.)

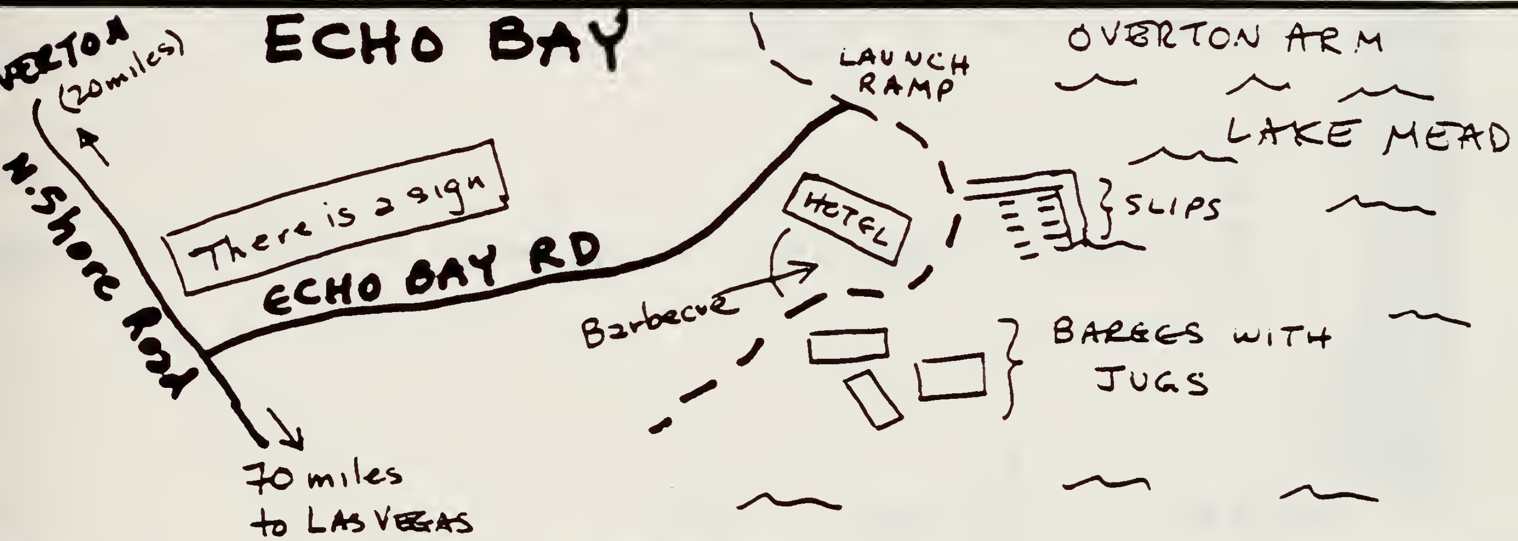
* * *

SUNSET MARINE & TACKLE

565-0696



ECHO BAY



There will be a recorded message with updates, starting about 22 MAY

798-0575

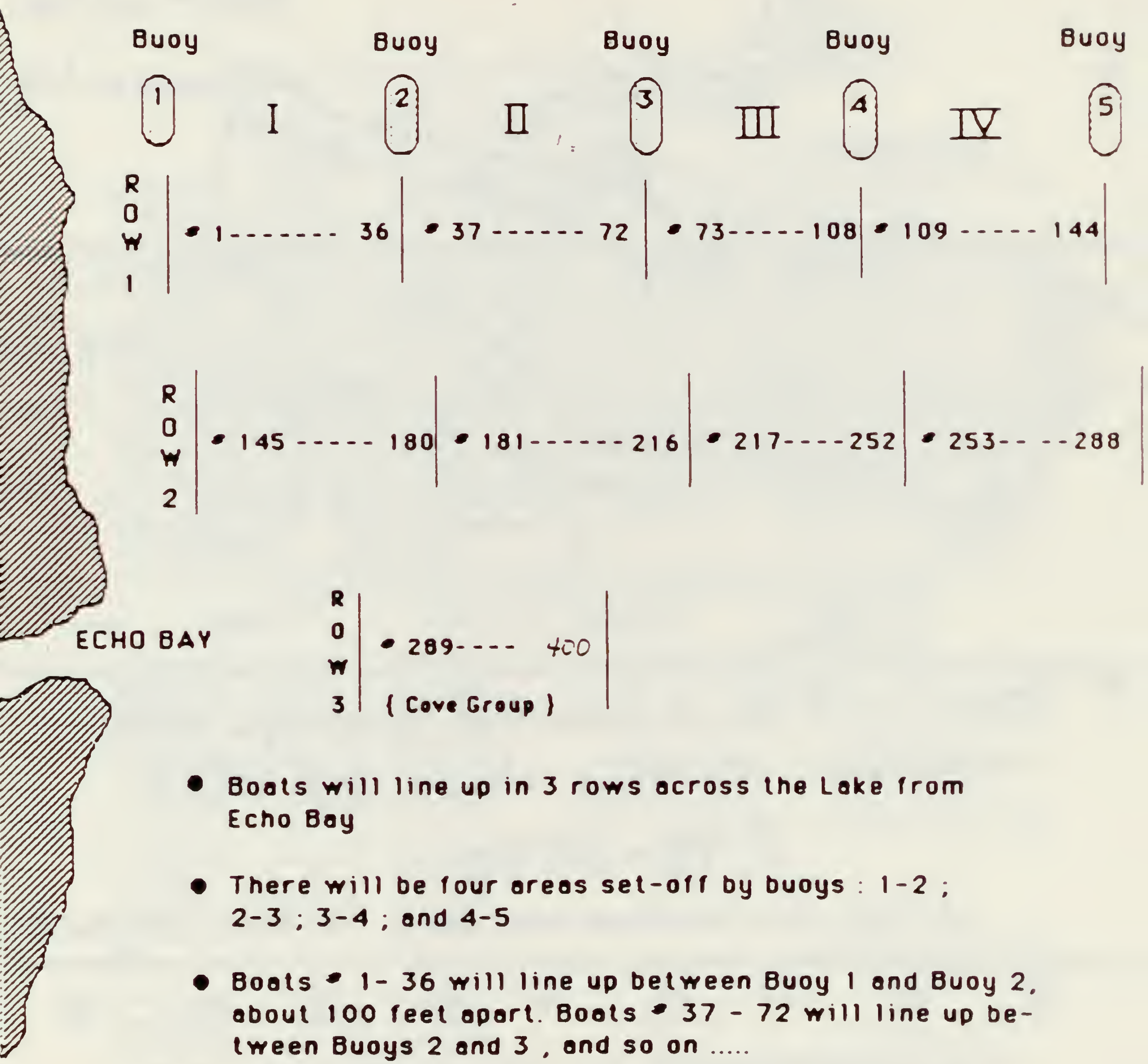
(You can leave a message if it's urgent)

* * * * * * * * *

IMPORTANT — BOATERS

lease find your boat number and make a large (8" x 10" is OK) sign with this number. Attach it to your boat so it is visible from the front

FERTILIZATION FLOTILLA DIAGRAM



- Boats will line up in 3 rows across the Lake from Echo Bay
- There will be four areas set-off by buoys : 1-2 ; 2-3 ; 3-4 ; and 4-5
- Boats • 1- 36 will line up between Buoy 1 and Buoy 2, about 100 feet apart. Boats • 37 - 72 will line up between Buoys 2 and 3 , and so on .....
- Launch at the time assigned on your boat identification form, and then either
  - -move offshore out of the way of launching and loading operations
  - -find an empty spot along the docks to tie up or
  - -beach your boat, there are many convenient sites in Echo B
- But , make sure you have your fertilizer and are in your proper position by 9 AM , Saturday May 30, 1987

APPENDIX 2

Additions and Revisions to the Proposed 1988 Research Design, as of March 1988.

Additions and Revisions to Proposed 1988 Research Design, as of March 1988.

The research design set out in the January 1988 Proposal (see Appendix 1) has been the subject of peer-review by a series of scientists with expertise in limnology, fisheries biology and natural resource management. The Proposal has also been extensively discussed on a more informal level with scientists from both within the Environmental Research Center of UNLV and outside organizations. As a result of this scientific input, a number of modifications have been made to the original research design. The principal modifications are summarized below. It is proposed to maintain these changes through the 1989 experiment, and further modifications to the research design may be made for that year's project. It is emphasized, however, that a) the series of major objectives detailed in the January 1988 proposal will not be changed, and b) any modifications to the monitoring program will not compromise the scientific evaluation of the project, from either a fisheries or a water quality perspective.

Monitoring Stations: A new down-lake control station (F-5A) has been added to the monitoring program, since F-5 in 1987 proved to be too close to the fertilized region to act as an adequate control. All the routine monitoring previously planned for station F-5 (see Appendix 1) will now be carried out at station F-5A. Sampling for a reduced parameter set (epilimnetic nutrients and chlorophyll-a) will be done at station F-5. As noted in Section 4 of this EA, an ideal control is effectively impossible to establish for a large-scale, *in situ*, experiment such as the one here proposed. The behavior of the down-lake control stations (Virgin Basin and F-6) in 1987, however, coupled with the process-oriented emphasis of the proposed research, strongly support the contention that the experimental design is satisfactory for the required scientific evaluations.

In addition to the new F-5A station, an extra up-lake station, F-0, located in the Virgin Bowl, has been added in order to monitor temporal variation in water quality of the Virgin River, the major tributary to the Overton Arm.

Shad Nutritional Condition: An additional study has been added to the research program in which the nutritional condition of shad will be monitored at the histological level for evidence of larval starvation. This approach has been used frequently in marine studies and, on one occasion, in an investigation of shad-zooplankton interactions in a southwestern reservoir (18). The approach is also being used to study the impact(s) of reduced levels of primary production on the survival of larval and juvenile fish in the Sacramento/San Joaquin delta (19).

Taste and Odor (T & O) Monitoring parameters: The originally proposed monitoring of T & O parameters (Appendix 1) has been modified, based in part on input from the Metropolitan Water District of Southern California (MWD; letter from M.J. McGuire [MWD] to A. O'Neill [NPS], dated 3/25/88).

Threshold odor number (TON) will be used as the sensory analytical method for T & O. A refined method, flavor profile analysis, has recently been developed by MWD for drinking water monitoring (22). While this method provides a more detailed characterization of odors in water, it is not currently standard methodology for most water suppliers in the U.S. In view of this, and the fact that the 1987 data base indicated that fertilization at the proposed levels will not significantly impact water odor, it is considered that TON analyses will adequately evaluate T & O in the proposed 1988 and 1989 experiments.

Monitoring of benthic algae has been added to the proposed 1988 and 1989 research, in order to determine if any significant growths of odor-causing blue-green algae (e.g., *Oscillatoria curviceps*) result from fertilizer additions. This monitoring will represent an extension of a research program already in operation by UNLV in which littoral and benthic plant communities are being surveyed. Three representative sites will be chosen in each of the treatment (F-2 -- F-4) and control (F-5A -- F-6) regions. The sites will be surveyed by divers to a depth of 8-15 m (depending on light penetration) and grab samples of periphyton will be collected (the number of samples will depend on spatial heterogeneity at the site). These samples will be analyzed for species composition and relative abundance. It is noted that previous work on the periphyton communities of Lake Mead has not demonstrated the presence in this system of *Oscillatoria* spp. (23). *Oscillatoria* is apparently a genus of primary concern in water supply reservoirs of the lower Colorado basin.

Phytoplankton analyses are already part of the proposed 1988 and 1989 research programs. Analyses will be carried out to the species level (as was also done for the 1987 experiment).

2-methylisoborneol (MIB) and geosmin are the two earthy/musty odorants of primary concern to MWD. In view of the fact that i) no *Oscillatoria* species have to date been recorded from the Lake Mead periphyton community (23), and ii) no odor problems were detected in the 1987 experiment, it is considered unnecessary to routinely analyze water samples for specific odorants during the 1988 and 1989 experiments. However, if i) significant growths of potentially odor-causing periphyton species are observed, and/or ii) routine TON analyses demonstrate a significant odor problem, additional water samples will be collected for analysis of MIB and geosmin by closed loop stripping analysis.

The schedule and sampling sites for the T & O monitoring program are summarized in Table 5. The series of sampling stations is considered satisfactory for demonstrating any potential T & O problems associated with the proposed artificial fertilization. Inclusion of stations in Boulder Basin and Las Vegas Bay would provide no additional or reliable information on the impact(s) of artificial fertilization on downstream T & O, given the major perturbing influence of wastewater discharge into the lower basin.

Trihalomethanes: The originally proposed monitoring program for THM precursors (Appendix 1) has been modified following input from MWD. THM precursors will be measured using the Simulated Distribution System Disinfiction By-Products (SDSDBP) procedure as proposed by MWD, if it is considered feasible to establish this methodology within the Quality Assurance Laboratory of the Environmental Research Center, UNLV. If adoption of this methodology is not feasible, total THM formation potential will be measured using the standard US EPA methodology (method 510.1). Use of this methodology is justified since i) it is the current standard, and ii) it essentially provides a conservative (= worst case) estimate of THM precursor concentrations.

The four principal THM compounds will be quantified (i.e. chloroform, bromodichloromethane, chlorodibromomethane and bromoform). The proposed 1988 and 1989 monitoring programs do not include measurement of other disinfection by-products. It is considered that inclusion of these substances is not warranted with respect to evaluating the impacts of the proposed two years of research on drinking water quality. Although these by-products were included in the recently published drinking water priority list (25), they are not currently subject to federal regulation and it is unlikely that they will become regulated before the completion of this research program. It is also noted that SNWS, the drinking water utility that is closest to the Overton Arm treatment area, apparently does not routinely carry out and/or publish analyses of non-THM disinfection by-products (14).

Although it is not deemed necessary to include non-THM disinfection by-products in the 1988 and 1989 monitoring programs, the Lake Mead Limnological Research Center is currently developing a collaborative research program with the Quality Assurance Laboratory of the Environmental Research Center, UNLV, which will focus on the interrelationships between various limnological parameters (e.g. chlorophyll concentration and phytoplankton species composition) and levels of THM and other disinfection by-product precursors along various trophic gradients in Lake Mead. It is anticipated that this additional study will provide detailed information that could be of use in the management of Lake Mead and other lakes in the future. It is emphasized, however, that the monitoring program as detailed in Appendix 1 and in this appendix is considered fully adequate to address water quality impacts as they relate to the proposed 1988 and 1989 experiments.

Sampling stations and schedules for THM monitoring are summarized in Table 5. The series of sampling stations is considered entirely adequate for demonstrating any potential impacts on total THM formation potential associated with the proposed fertilization. Inclusion of stations in Boulder Basin and Las Vegas Bay would provide no additional or reliable information on the impact(s) of artificial fertilization on downstream THM precursor concentrations, given the major perturbing influence of wastewater discharge into the lower basin.

APPENDIX 3

Salinity Evaluation of the 1987 Overton Arm Fertilization Project

THE OVERTON ARM , LAKE MEAD
FERTILIZATION PROJECT

-SALINITY EVALUATION-

Dr. Richard Axler
Dr. Larry Paulson

Lake Mead Limnological Research Center
Environmental Research Center
Museum of Natural History
University of Nevada-Las Vegas
Las Vegas , Nevada 89154

January 1988

All available evidence has shown that fertilization of the Overton Arm of Lake Mead, at the proposed levels of ~ 20 µg P/L using liquid ammonium polyphosphate fertilizer (formulation 10-34-0), will **not** significantly increase the salinity of the lakewater. This conclusion is based on calculations, laboratory studies, pilot-scale experiments conducted in Cathedral Cove, Lake Mead in August and September 1986, and the 20,000 acre test fertilization conducted in the Overton Arm of Lake Mead in May 1987 (Axler et al. 1987a, 1987b ; Axler and Paulson 1987 ; LMNETC 1987; Paulson et al. 1988).

It should also be noted that neither ammonium nor phosphate are routinely considered to contribute to the salinity of water bodies. They are nutrients which, even immediately after fertilization when surface concentrations are as high as they can possibly be, will be present at levels thousands of times lower than the major components of the salt load of Lake Mead water. This fact is either explicitly stated or inferred in virtually every limnology and water quality textbook. Dr. R. Wetzel states on page 143 of his textbook *Limnology* (one of the most widely used texts in North America) : " The concentrations of four major cations, Ca, Mg, Na, K, and four major anions HCO_3, CO_3, SO_4, and Cl, usually constitute the total ionic "salinity" of the water for all practical purposes. The concentrations of ionized components of other elements such as nitrogen (N), phosphorus (P), and iron (Fe), and numerous minor elements are of immense biological importance, *but from the standpoint of the composition of water they are small*." Similarly, Dr. G.E. Hutchinson, who is generally considered to be the "father" of modern limnology , writes on page 553 of Volume I - *Limnology* : "... *it would be more satisfactory to define salinity as the concentration of the Na , K , Mg , Ca , CO_3 , SO_4 , and halide (Cl) present, all bicarbonate being converted to carbonate* ."

Lake Mead Pre-Fertilization Study -Cathedral Cove, 1986

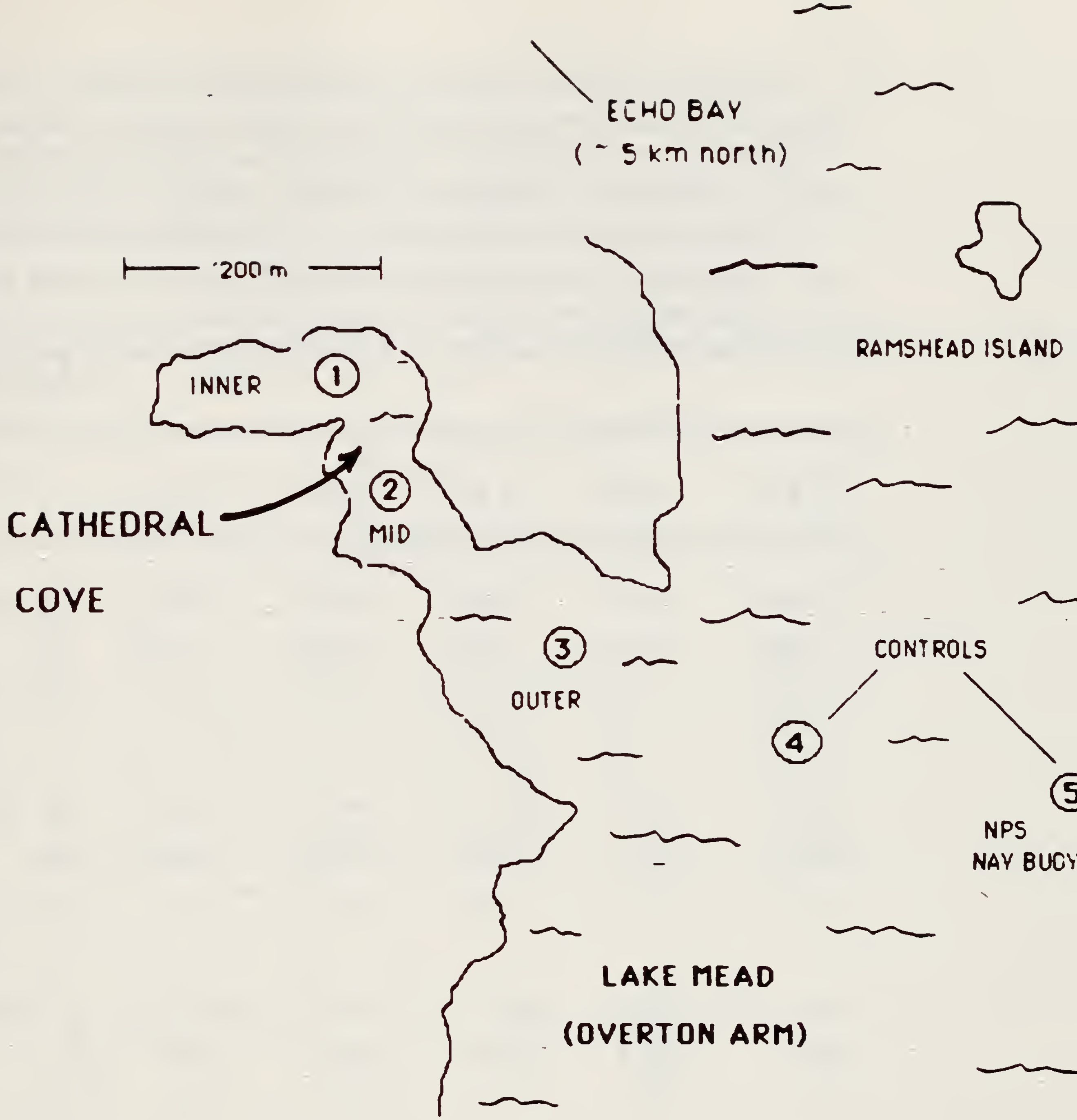
This study was conducted by the Lake Mead Limnological Research Center (LMLRC) from May 1986 to September 1987 and was funded by the U.S. Bureau of Reclamation (Axler et al. 1987a). In addition to laboratory studies which showed that the proposed Lake Mead fertilization would not produce a measurable increase in salinity, two test fertilizations were conducted in Cathedral Cove, Lake Mead (~ 32 acres in area) which is located near the center of the Overton Arm , ~3 km south of Echo Bay (see

Figure 1).

Field measurements of specific electrical conductivity (EC) before, during, and after the fertilizations showed that salinity was not significantly increased. Even in the inner portion of Cathedral Cove, where almost 3x the proposed dose for the Overton Arm was applied in September 1986, we did not observe an increase in EC. During the first cove experiment, in August 1986, within 2 hours of the actual fertilization we conducted an intensive survey of the inner cove. Eight *Hydrolab* (a commercially available water quality analyzer which is calibrated daily) profiles of temperature, pH, conductivity, and D.O. were measured along an east-west transect of the inner cove and no significant differences were found (Table 1).

The field EC data for cove studies were further corroborated by complete analyses for TDS, Na, K, Ca, Mg, HCO_3, CO_3, Cl, SO_4, and SiO_2 performed by the U.S. Bureau of Reclamation (Table 2). EC was also determined independently in this laboratory. The analyses were performed on two sets of 0-5 meter vertically integrated composite water samples, one from each fertilization experiment. They were sampled approximately 48 hours after the initial application to allow the wind to vertically mix the fertilizer throughout the epilimnion. The five samples corresponded to the five station transect used for all limnological monitoring in the study. Stations 1, 2, and 3 were inside the cove, and stations 4 and 5 were the designated control sites outside the fertilized cove (see Figure 1).

The data clearly show that neither salinity, as estimated by TDS and EC, nor any of the major anions and cations were significantly increased by fertilization with either granular (diammonium phosphate plus ammonium nitrate) or liquid (ammonium polyphosphate plus ammonium nitrate) formulations. This finding is consistent with the field measurements of EC discussed above. Only if extremely high doses of these fertilizers were applied, orders of magnitude higher than those proposed (or ever considered) for the Overton Arm experiments, could one reasonably expect to measure an effect on the salinity of Lake Mead water.



Note Station LM 18 (Lower Overton) is located ~ 10 km south from station 5 in the main channel

Figure I Cathedral Cove, Lake Mead Sampling Stations

Table I. Specific electrical conductivity (EC, in umhos/cm) in the epilimnion of Cathedral Cove, Lake Mead during fertilization pilot studies in 1986 Data are from the inner cove (#1), mid-cove (#2), outer-cove (#3), and control stations #4 and #5 in the Overton Arm outside the cove. Data expressed as mean ±s.d. for n depths within the mixed layer, Z_e, before and after the fertilizations on 25 August and 22 September. The data for stations 1 and 2 for August 25 were collected immediately after fertilizing these regions. Stations 3, 4, and 5 were sampled just prior to fertilization.

		STA 1	STA 2	STA 3	STA 4	STA 5
8/24:	Z_e	>9m	13m	13m	14m	14m
	EC_e	807± 1	806± 2	806±1	805±1	804±1
	n	10	13	14	15	15
8/25:	Z_e	10m	12m	11-12m	12m	12m
	EC_e	824±9	830±10	827±13	822±9	819±9
	n	11	13	12	13	13
8/26:	Z_e	11-12m	11-12m	11-12m	12m	12m
	EC_e	835±7	840±3	836±5	836±5	839±4
	n	12	12	12	13	13
9/21:	Z_e	>15m	16m	17m	17m	16.5m
	EC_e	802±1	801±1	801±1	802±1	800±2
	n	16	17	18	18	18
9/23:	Z_e	>15m	19m	18^+m	19m	18^+m
	EC_e	802±0	800±3	801±2	801±2	801±2
	n	9	11	9	12	13

TABLE 2 . Summary of the results of salinity analyses performed by the U.S. Bureau of Reclamation on water samples collected during the Cathedral Cove, Lake Mead pilot-scale fertilizations in 1986. The sampling dates are two days following enrichment with granular fertilizer in August and with liquid fertilizer in September 1986, respectively. Stations 1, 2 and 3 were located within the fertilized area, and stations 4 and 5 were control areas outside of the cove. Field pH and electrical conductivity (EC) are averages taken from vertical profiles throughout the epilimnion by UNLV. All other data were determined in the USBR, Lower Colorado Region, Soil and Water Laboratory on 0-5 m depth-integrated composite water samples. EC in µmho/cm, all other data in mg/l.

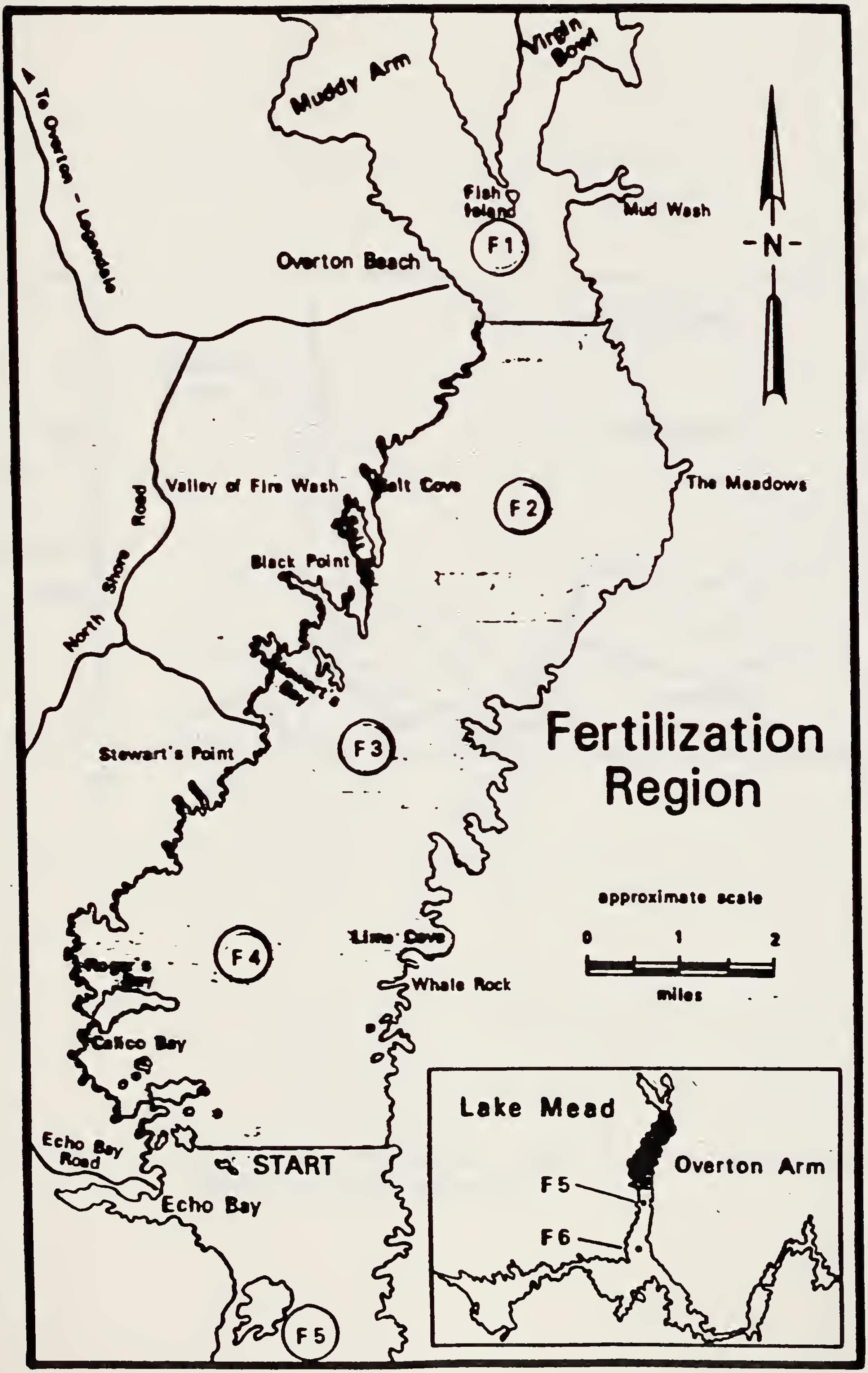
DATE	STATION	pH Field	pH Lab	EC Field	EC Lab	TDS	Na	K	Ca	Mg
27 Aug 1986	1	8.0	7.4	840	848	584	66	4	68	26
	2	8.5	7.6	839	846	587	66	4	68	26
	3	8.4	7.6	840	846	589	66	4	69	26
	4	8.4	7.6	844	843	583	66	4	68	26
	5	8.3	7.8	843	845	562	66	4	68	26
24 Sep 1986	1	8.4	7.4	802	834	560	64	4	68	26
	2	8.4	7.4	802	829	553	63	4	68	26
	3	8.4	7.4	802	832	558	63	4	68	26
	4	-	7.5	-	830	555	63	4	68	26
	5	8.3	7.7	801	828	552	63	4	67	25

DATE	STATION	HCO_3	Cl	SO_4	SiO_2	USBR Lab. #
27 Aug 1986	1	149	60	228	9	86-3748.
	2	151	59	230	9	86-3749
	3	144	57	230	8	86-3750
	4	142	64	226	9	86-3751
	5	156	53	223	9	86-3752
24 Sep 1986	1	146	57	223	8	86-3753
	2	151	53	216	8	86-3754
	3	156	53	216	9	86-3755
	4	142	57	223	8	86-3756
	5	154	59	218	8	86-3757

Lake Mead Fertilization Study- Overton Arm, 1987

This study is currently being conducted by the LMLRC, in cooperation with the Lake Mead Nutrient Enhancement Technical Committee, and is funded by the National Oceanic and Atmospheric Administration and the Nevada Department of Wildlife. The first year of the proposed three-year experimental research program involved fertilizing approximately 20,000 acres of the Overton Arm of Lake Mead with ~20µg P/L as liquid ammonium polyphosphate on May 30, 1987 (see Figure 2 for study area and sampling stations). No adverse impacts on the beneficial uses of the lake resulted from the fertilization, as predicted in the Environmental Assessment for the project (LMNETC 1987, Axler and Paulson 1987).

In particular, we also note that the fertilizer addition (again) did not significantly increase the salinity of the lake , a concern which arose during the comment period for the Environmental Assessment. This topic was thoroughly addressed in the Pre-Fertilization Study and further demonstrated in the present study. It is apparent from Figure 3, Figure 4, Table 3, and Table 4 that although differences between stations existed before and after the application, fertilization did not increase the electrical conductivity, TDS, or major ion (composition at individual stations within the fertilization region. The north-south gradient in EC in the Overton Arm has been noted historically and is maintained by influences from the Virgin and Muddy Rivers.



Fertilization Region
To Overton - Logandale
Muddy Arm
Virgin Bowl
Fish Island
Mud Wash
F1
Overton Beach
N
Valley of Fire Wash
Salt Cove
F2
The Meadows
North Shore Road
Black Point
Stewart's Point
F3
approximate scale
0
1
2
miles
F4
Lime Cove
Rogers Bay
Whale Rock
Calico Bay
Echo Bay Road
START
Echo Bay
F5
Lake Mead
Overton Arm
F5
F6

Figure 2.

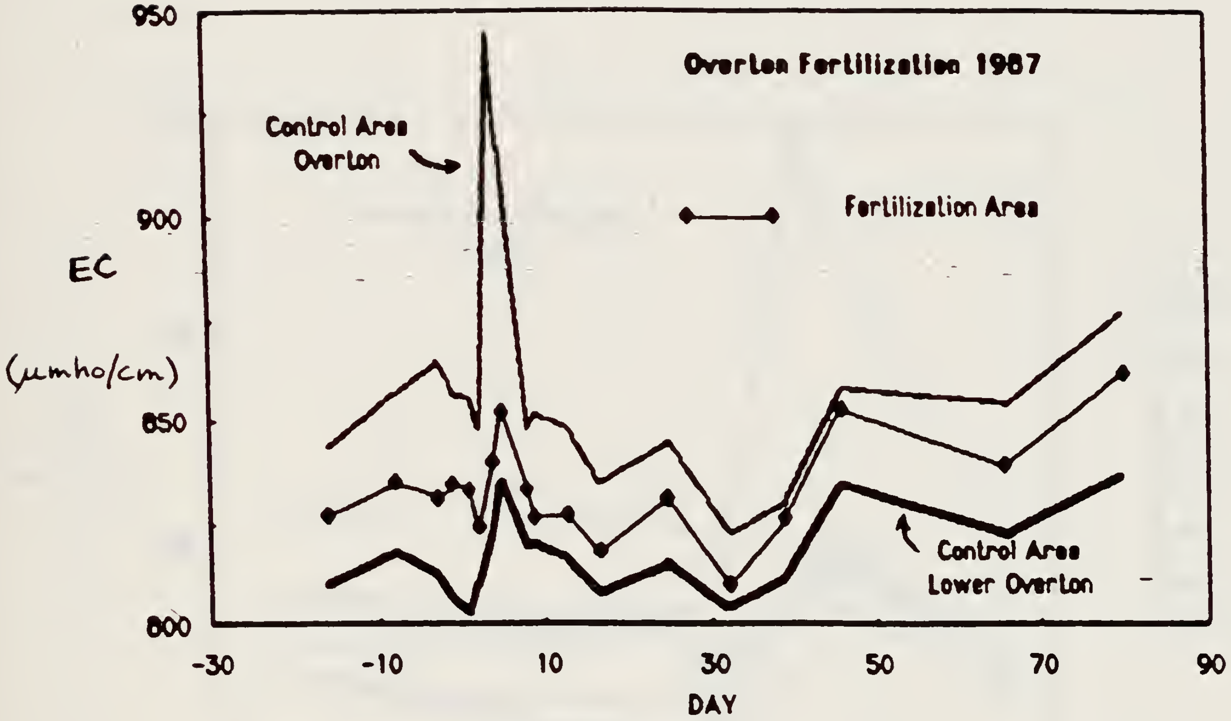


Figure 3. Overton Arm Fertilization, 1987. Electrical conductivity (EC). (Note - truncated EC scale).

OVERTON ARM FERTILIZATION 1987

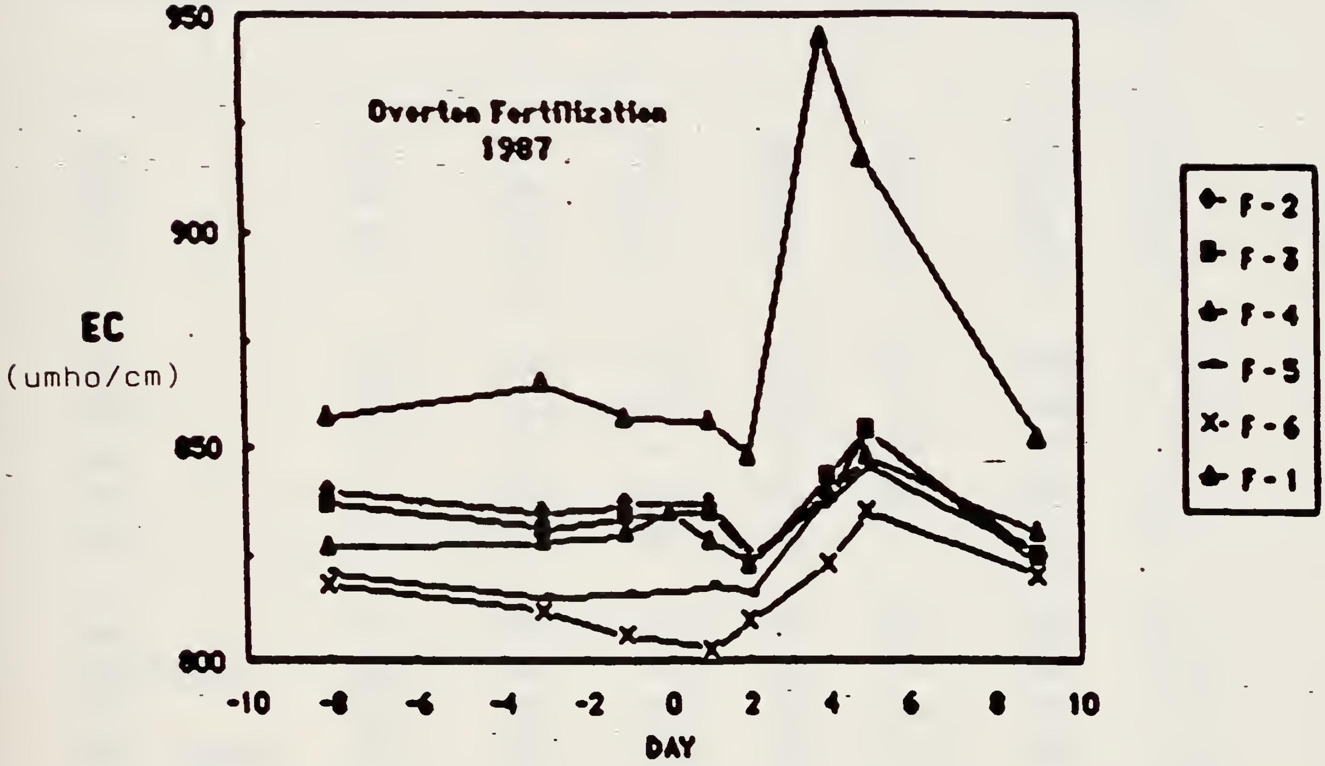


Figure 4 . Electrical conductivity for Overton Arm Fertilization stations. EC in umhos/cm averaged over the upper 5m. Fertilized region included F2, F3, and F4. Day 0= May 30, 1987.

Table 3 . Results of U.S. Bureau of Reclamation (lower Colorado Region, Soil and Water Laboratory, Boulder City, NV) analyses for major anions and cations (mg/l), electrical conductivity (EC, in µmhos/cm), pH , and TDS (mg/l) from the Overton Arm on May 31, 1987 (one day after fertilization). Samples are 0-5m composites . Also tabulated are EC field measurements (mean values from 0-5m) taken at the same time as the water collection and on May 29, the day before the fertilization. FZ = mean of F2 + F3 + F4.

PARAMETER	N. Control	Fertilized Zone			$\overline{FZ}$	S. Controls	
	F1	F2	F3	F4	F2/3/4	F5	F6
Ca	75	77	75	73	75	72	71
Mg	26	26	26	25	26	25	24
Na	68	67	67	66	67	64	63
K	5	5	5	5	5	5	5
SO4	228	216	216	218	217	209	199
HCO3	144	124	112	137	124	134	146
CO3	12	12	14	19	15	17	10
Cl	67	57	60	59	59	55	51
SiO2	9	8	8	9	8	9	8
pH	8.4	8.5	8.5	8.5	8.5	8.5	8.4
TDS (evap)	588	579	577	575	577	555	550
EC	865	850	851	843	848	834	813
EC* (UNLV)	856	837	835	828	833	818	803
EC** (UNLV)	857	837	834	830	834	816	806

---

* Field measurement on May 31, 1987 at time of USBR water collections

** Field measurement on May 29,1987 prior to fertilization

Table 4. Results of U.S Bureau of Reclamation (Lower Colorado Region, Soil and Water Laboratory, Boulder City, NV) analyses for major cations and anions (mg/l), electrical conductivity (EC, in µmhos/cm) and TDS (mg/l) from the Overton Arm. Station F4 in the fertilized zone and F6 at the southern control area were monitored monthly as stations LM19 and LM18, respectively, for the USBR in 1986 and 1987. Data from 5-31 are part of a set that also includes F1, F2, F3, and F5 which were all sampled one day after fertilization. All samples were surface water except on 5-31, which were 0-5m composites.

	CA		MG		NA		K	
DATE 1987	F4	F6	F4	F6	F4	F6	F4	F6
3-18	68	67	23	23	61	61	3.1	3.1
4-15	70	70	24	24	64	62	3.1	3.5
5-14	71	69	24	24	64	63	3.1	3.1
5-31	73	71	25	24	66	63	5.0	5.0
6-17	66	68	25	25	65	64	5.1	5.1

	SO4		HCO3		CO3		CL	
3-18	196	194	165	159	0	0	51	47
4-15	205	192	161	160	0	0	55	53
5-14	211	198	151	160	11	6	54	51
5-31	218	199	137	146	19	10	59	51
6-17	212	208	117	119	13	12	53	52

	EC		TDS	
3-18	796	798	522	521
4-15	823	810	545	521
5-14	825	805	526	512
5-31	843	813	575	550
6-17	818	820	545	527

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APPENDIX 4

Estimating the potential for shad biomass production resulting from artificial fertilization.

APPENDIX A

Estimating the potential for shad biomass production resulting from artificial fertilization.

ESTIMATING THE POTENTIAL FOR SHAD BIOMASS PRODUCTION RESULTING FROM ARTIFICIAL FERTILIZATION

In order to estimate the potential contribution of artificial fertilization to increasing the forage base of Lake Mead we first calculate an approximate lower limit to the shad biomass produced from the proposed spring/summer fertilizer applications.

☐ The proposed experiments will add a total of 20,000 gallons of ammonium polyphosphate to 18,950 acres (7669 ha) of the Overton Arm during the main growing season. This is equivalent to an addition of 2.01 kg P/ha.

☐ Since Lake Mead is a P-limited system, it is assumed that all of the added P goes into algal biomass. Based on a C:P ratio in "healthy" phytoplankton of ≈ (40-100):1 (see ref. #20), the added P would produce between 80 (=40 x 2.01) and 200 (=100 x 2.01) kg algal-C/ha.

☐ To estimate the biomass of shad produced from this amount of algae, we here assume 1) a 10% transfer efficiency between trophic levels, and 2) that shad feed entirely on herbivorous zooplankton. The amount of C at the shad level is therefore within the range: 0.8 (=80 x 0.01) - 2.0 (=200 x 0.01) kg C/ha.

☐ Assuming 1 gram C is equivalent to 10 grams wet weight of fish (4), the biomass of shad produced from the proposed fertilizer loading is: 8 - 20 kg/ha.
Note: These estimates represent an approximate lower limit of shad production (see below).

In order to place this lower limit estimate into a "real lake" context, we use results from the only study to date on Lake Mead that has attempted to document absolute fish densities throughout the water column (21). This is a hydroacoustic survey of the upper basin of the reservoir conducted in 1986-87.

We assume that all fish located in this survey were shad (approximately 96% of the "hits" were estimated as shad-sized fish [21]). The table below presents densities of shad per unit area in the Gregg and Temple Basins on each of the four sampling dates. Areal densities have been calculated by weighting the depth-specific volumetric densities provided in (21). An average length and weight for an individual shad on each date is estimated from knowledge of threadfin shad life history. (While these latter two estimated parameters are only "educated guesses", any potential error would not significantly affect our overall conclusions from this exercise). Using the estimated individual mean biomass, areal densities are converted to biomass (kg/ha).

	# fish / 10^6 m^2 (mean of surveys 1 and 2)			
	Apr. 86	July 86	Oct. 86	Jan. 87
Gregg Basin	3,230	7,165	15,203	22,755
Temple Basin	2,933	1,258	68,945	4,925
Assumed:				
Mean length (mm):	80	40	50	80
Mean weight (g):	5	2	2.5	5
	Estimated shad biomass (kg/ha)			
Gregg Basin	0.162	0.143	0.380	1.138
Temple Basin	0.147	0.025	1.724	0.246

It can be seen that the maximum estimated shad biomass (Temple Basin in October) is considerably lower than the lower limit estimate of the potential shad production resulting from artificial fertilization.

The estimated biomass of shad produced from fertilization (8-20 kg/ha) is, as previously noted, likely to be a lower limit estimate for the following reasons:

1) The 10% transfer efficiency between trophic levels is based on energy transfer. In the proposed experiments, however, phosphorus is added to a P-deficient system. Recycling of P within the planktonic components of the system would probably substantially increase the proportion of the original P addition that "reaches" the shad level, with a corresponding increase in the biomass of shad produced.

2) Much of the proposed research is designed around the hypothesis that enhanced shad production will occur if food abundance is boosted around the time that the larval/post-larval stages are moving into the pelagic region of the lake from the littoral spawning sites. This outward movement appears to coincide with the dramatic decrease

in zooplankton densities typically seen in Lake Mead (and other lakes) at this time of year. As a result, shad larvae reaching the pelagic zone behind the first "wave" of the year's larval recruits probably experience low food abundance, which in turn may significantly impact their survival. If this period is critical to shad in Lake Mead, any increase in planktonic production at this time is likely to have an impact on the year class strength that could be completely disproportionate (in a positive sense) to the amount of phosphorus added to the system and the resulting enhanced rates of algal production.

CONCLUSION: Artificial fertilization of the Overton Arm at the levels proposed for the 1988 and 1989 research has the potential for causing a significant increase in the biomass of threadfin shad relative to "background" levels in the lake.

APPENDIX 5

List of persons attending scoping meeting for 1988/1989 EA, convened by NPS, 18 March 1988

List of persons attending scoping meeting for 1988/1989 EA, convened by NPS, 18 March 1988.

1. M. A. Coffey, National Park Service, Lake Mead NRA
2. D. Sundie, Arizona Department of Water Resources
3. P. Coffin, Nev. Dept. of Wildlife
4. J. Donaldson, Nev. Dept. of Wildlife
5. C. Neal, Central Arizona Water Cons. Dist.
6. D. Buck, Nevada Department of Wildlife
7. B. Angel, Calif. State Attorney General's Office
8. A.E. Hallenbeck, U.S. Bureau of Reclamation
9. D. B. Underwood, Colorado River Board of Calif.
10. D. R. Hetzel, Colorado River Commission
11. K. Tachike, Metropolitan Water Dist. of So. Calif.
12. F. Vendig, Metropolitan Water Dist. of So. Calif.
13. D. Baepler, UNLV
14. L. J. Paulson, UNLV (LMLRC)
15. P. Vaux, UNLV (LMLRC)
16. T. Liles, Arizona Game and Fish
17. A. O'Neill, Lake Mead NRA
18. G. E. Bunney, Lake Mead NRA
19. J. Cooper, Nevada Division of Environmental Protection
20. J. Hutchings, Nevada Department of Wildlife
21. F. Havis, C.C. Health Dist.
22. C. Newman, National Park Service
23. G. Mueller, Bureau of Reclamation
24. D. J. Rexing, Las Vegas Valley Water Dist.
25. J. T. Monsevitz, Las Vegas Valley Water Dist.
26. R. Sullivan, Las Vegas Valley Water Dist.
27. T. Burke, Bureau of Reclamation
28. J. Brown, Bureau of Reclamation
29. J. Landy, U.S. EPA - Reg. IX
30. M. J. McGuire, Metropolitan Water Dist. of So. Calif.
31. N. Sikes, Nat. Park Ser. Lake Mead NRA
32. D. Askenaizer, Metropolitan Water Dist. of So. Calif.